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ENERGY SELF-SUFFICIENT ECO-VILLAGE

Utilization of wind energy

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Abstract

There is clear demand for developing renewable energy due to global warming concern and increasing price of fossil fuel energy. Wind energy is considered as the most important and applicable renewable energy compared to other types of renewable energy system, such as solar energy and bioenergy. Energy self-sufficient eco-village has become the unique model because of the heat and electricity is supplied by renewable energy systems instead of conventional energy sources.

This thesis is commissioned by Tianjin Heng Sheng Xin Yuan Construction Company-No.15 Branch Office, China. This thesis concentrates on the characteristics of wind energy, the utilization and development of wind energy, as well as associated economic, social and environmental factors. In addition, Feldheim energy self-sufficient eco-village is analyzed as a case study in order to explore the possible utilized renewable energy systems to support energy independency, to analyze the peculiarities of establishing a successful energy independent eco-village, to discuss whether the similar villages can be built elsewhere. This thesis is studied based on scientific literature review and internet research.

According to the research, an energy self-sufficient eco-village not only brings economic benefits, but also ecological and social benefits. Similar energy independent eco-village with Feldheim village can be built in a place with similar natural conditions. Energy independency is a long-term goal, and investors and governments should support associated financial, legal and technical aspects of the new development and innovation.

Subject headings, (keywords)

energy self-sufficiency, energy independency, wind energy, eco-village, Feldheim

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CONTENTS

1 INTRODUCTION

Increasing global warming concern is the dominant driving factor for the development of renewable energy. In addition to global warming issue, price of fossil fuel energy is continuously increasing, which results in a growing burden for private individuals, companies, organizations, and municipalities. Meanwhile, the renewable energy techniques have become more and more important and motivating, due to environmental friendly characteristics and economic reasons. By integrating renewable based energy supply concepts, nowadays several existing eco-villages are able to reach both sustainable energy and a cost-effective alternative to conventional fossil fuel, such as coal, oil, natural gas and nuclear power. (Knape, 2010.)

The traditional model of large centralized power plants supplying electricity and heat to consumers is changing to one where increasing amounts of decentralized energy and heat is generated nowadays. In particular, wind and solar photovoltaic (PV) are the two major of renewable technologies that change the balance of where the energy is generated and grid distribution. Thus, wind energy and solar energy are chosen as the most popular technologies to support regional energy independence.

Energy self-sufficient eco-villages differentiate from traditional villages by relying on renewable energy systems to meet electricity and heat demand instead of using conventional coal-based power plants and fossil fuel-based power plants to generate energy. This transition not only brings ecological and environmental benefits, but also social and economic benefits. Among existing energy independent eco-villages nowadays, Feldheim is a successful example because of the unique grid and no conflicts with local villagers in the entire implementing process of renewable energy systems. Therefore, Feldheim energy independent eco-village is chosen as a case study in this thesis. In addition, wind energy is discussed as the most important and applicable renewable energy to support energy independence.

This thesis is commissioned by Tianjin Heng Sheng Xin Yuan Construction Company-No.15 Branch Office, China in 2014. The purposes of this thesis is to explore the innovation and utilization of suitable renewable energy technologies for development of energy self-sufficient eco-village at local level, to discuss the associated economic factors, and whether this kind of eco-village can be built elsewhere in the world. Furthermore, the following research questions are covered and discussed in this thesis.

- What are the factors involved in planning and implementing stages of energy independent eco-villages? What are the related driving factors and barriers of establishment?
- What are the peculiarities of establishing a wind energy system? What are the characteristics and economic factors of wind energy? What kind of environmental and social impacts wind energy would bring?
- Why Feldheim energy independent eco-village can be so successful and what are the economic, ecological and social benefits of such an eco-village?
- Whether similar energy independent eco-village can be built in China and what is the potential, if the wind characteristics and climate permit?

On the basis of scientific reading and internet research, the essential knowledge of building an energy independent eco-village with major utilization of wind energy is studied in this thesis, as well as the information of technical and socio-economic factors of Feldheim village in Germany. The assessment of success of Feldheim village is based on literature review and official website research.

2 ENERGY INDEPENDENT VILLAGE

Independent energy generation is the key difference between traditional villages and modern energy self-sufficient villages. Except the suitable installed systems for producing electricity and heat, other key economic factors and social factors must be considered for building a successful cost-effective and eco-friendly village. In this chapter, the factors involved in the planning and implementing stages of energy independent villages are introduced, as well as the drivers and barriers for energy self-sufficient eco-village projects.

Energy self-sufficient eco-villages are typically constructed in three regions: where society development and energy demand rely on import conventional expensive coal-based or other fossil fuels-based energy; where electricity or heat supply has much higher cost than for those consumers located in urban areas; remote communities which often have poor grid stability. In the last few decades, the cost of renewable energy has decreased and cost-effectivity has increased. Management of a small grid with significant renewable energy generation is an excellent application for smart grid technologies in order to support energy independent eco-villages. Several energy self-sufficient eco-villages have been built with smart grid concept installation and operation, see table 1 below. (Bonifazi et al, 2013.)

TABLE 1. Examples of existing energy self-sufficient eco-villages (Bonifazi et al, 2013).

Village/Country	Electricity and heat generation	Other information
Feldheim Germany	Electricity-wind turbines, solar farm, biogas plant Heat-woodchip fired plant, biogas plant	Feldheim is Germany's first and only energy self-sufficient village. The power comes solely from a mix of 43 wind turbines, a woodchip-fired heating plant, a solar farm and a biogas plant that uses cattle and pig slurry as well as maize silage.
Wildpoldsried Germany	Electricity-windmills, solar Heat-wood pellet plant, biogas generators, oil heater at peak demand	Fuel savings are estimated about 160 m^3 of oil per year (from oil heaters no longer in use). CO^2 emission reduction was estimated at over 400 tonnes per year.
Samsoe Denmark	Electricity-wind turbines Heat-district heating plants, solar, wood chip, straw	The district heating plant in Nordby/Mårup receives heat from 2500 m^2 solar thermal array and a 900 kWh wood chip-fired boiler. The district heating plant is the only heating plant of its kind based on solar thermal and a wood chip-fired boiler.
Schönau Germany	Electricity-hydro, solar panels, wind turbines Heat-combined heat and power	Schönau is a small town in Germany's Black Forest mountains, with a population of 2500. The local energy cooperative bought the town electricity grid from the local regional energy provider, and now generates electricity and heat by using a number of technologies. The cooperative initially provided 1 GWh of energy to 1700 local customers.

As it can be seen in table 1, a biogas plant and a wood chip heating plant produce the heat in Feldheim village. The electricity supply mainly depends on wind turbines, solar farm and biogas plant. According to the statistics made by Energiequelle company (Energiequelle, 2014), especially a share of 96 % of total electricity output in Feldheim is generated by the installed 43 wind turbines. Therefore, wind energy will be emphasized as the most important type of renewable energy in this thesis.

2.1 Factors involved in energy self-sufficient village establishment

The considered factors involved in energy self-sufficient village establishment are investments, technical supports of planned and implemented renewable energy system, policy and regulations, and economic and ecological beneficial factors. Investors of an energy independent village could be private equity, community share, banks and financial institutes and grant funding sources. Technical supports of planned and implemented renewable energy system can be achieved from the following actors (Bonifazi et al, 2013):

- Renewable energy system supplier
- Grid equipment suppliers
- Integrators
- Grid operators

In order to provide the enabling environment for the development of energy self-sufficient villages, fiscal instruments and incentive mechanism are the main policies which can be offered by the government. For instance, examples of incentive mechanism are low-interest loan schemes, grants for energy self-sufficient village/ community projects and feed-in tariffs for both community and household projects. (Bonifazi et al, 2013.) Furthermore, an energy self-sufficient village does not only create the economic benefits with low price of generated energy, but also brings the ecological benefits and social benefits. For instance, increased local employment rate and decreased amount of GHG emissions generated from energy production are social and ecological benefits compared to conventional energy generation.

2.2 Driving factors

In addition to the policy mechanisms set by government, more driving factors are introduced in this section. The summary of driving factors is listed in below:

- Local income and employment rate

Local income is increased through the sale of generated electricity or heat and other associated raw materials. Local employment rate is increased.

- Promotion of energy self-sufficient villages on the international stage

The established independent energy system could bring the village to international stage and attract more investments and tourists.

- Strengthen the power of local control

Independent energy generation could help local communities to develop greater self-determination by the direct control of local resources.

- Environmental commitment

More individuals involved in the sustainable energy generation is a form to increase the share of social responsibility.

- Community cohesion

As benefits of implementing energy independent villages, increased investments and tourists would bring people together from different background and cause social cohesion.

- Innovative business models

Increased local income and investments could enhance the business models shift because of the development of sustainable energy generation. In addition, interesting self-sufficient energy systems might attract more experts to develop the innovative business models. (Bonifazi et al, 2013.)

2.3 Barriers

“Barriers are defined as forces or mechanisms which inhibit behaviors or investments that would increase the uptake of more energy efficient products” (Bonifazi et al, 2013). There are several barriers that affect the planning and implementation process of energy independent villages, and the summary of them is listed as following.

- Access to land

Most of renewable energy systems depend on the geographical peculiarities, especially solar energy and wind energy. Additionally, a large area is required to install the equipment of renewable energy, for instance, wind turbines.

- Access to capital

Implementation of an energy independent village requires amount of money, including fee for technical consulting by renewable energy supplier, the costs of application for planning and for licenses, the costs of renewable energy system installation and maintenance costs.

- Uncertainty of nature dependency

It is hard to guarantee the power output of renewable energy systems, in which working efficiency depends on weather conditions, for instance, solar energy and wind energy.

- Licences and regulation

The regulatory aspects can be extremely complicated for development of renewable energy projects. (Bonifazi et al, 2013.)

3 WIND ENERGY

Winds can be defined as movements of air masses in the atmosphere and are an indirect action of solar radiation falling on earth. Winds are generated primarily by temperature differences within the air layer due to differential solar heating. (Kalogirou, 2013.) Therefore, wind energy can also be considered as one form of solar energy. The performance and economics of a wind power plant can be determined by the wind characteristics in specified region, the magnitude of wind speed and its duration, and applied wind technologies. Thus, the wind characteristics should be analyzed as the first consideration for determining the suitability of a site for wind energy exploitation. (Kalogirou, 2013.)

In this chapter, more details are given mainly about wind resource and its characteristics, and how these can be evaluated in order to decide whether a site is suitable for wind energy development and utilization. In addition, a short description of wind energy characteristics and an overall analysis of different types of wind turbines are presented in this chapter, as well as economic factors of wind energy and the related adverse environmental and social impacts caused by wind-based power generation. (Kalogirou, 2013.)

3.1 Wind resource

As we know, the latitude of a location affects the energy per unit surface area received from the sun. Thus, different parts of the world receive different amounts of energy, and this characteristic causes temperature differences. In addition to temperature differences, wind is also caused by differences in pressure. Theoretically, the wind blows from high-pressure areas to low-pressure areas. Wind speed can be affected by both the height and the spacing of the roughness elements found on the surface of the earth. Because of the surface roughness, friction causes the wind speed to be slower when closer to Earth's surface. (Kalogirou, 2013.)

In order to estimate the performance of wind turbines accurately, various parameters need to be monitored and considered of the wind, including the mean wind velocity, wind directional data, variations about the mean in the short period, hourly, daily, seasonal and annual variations, and variations with height. These parameters are highly site specific and can only be determined with sufficient accuracy by measurements at a particular site over a sufficiently long period. (Walker & Nicholas, 1997.)

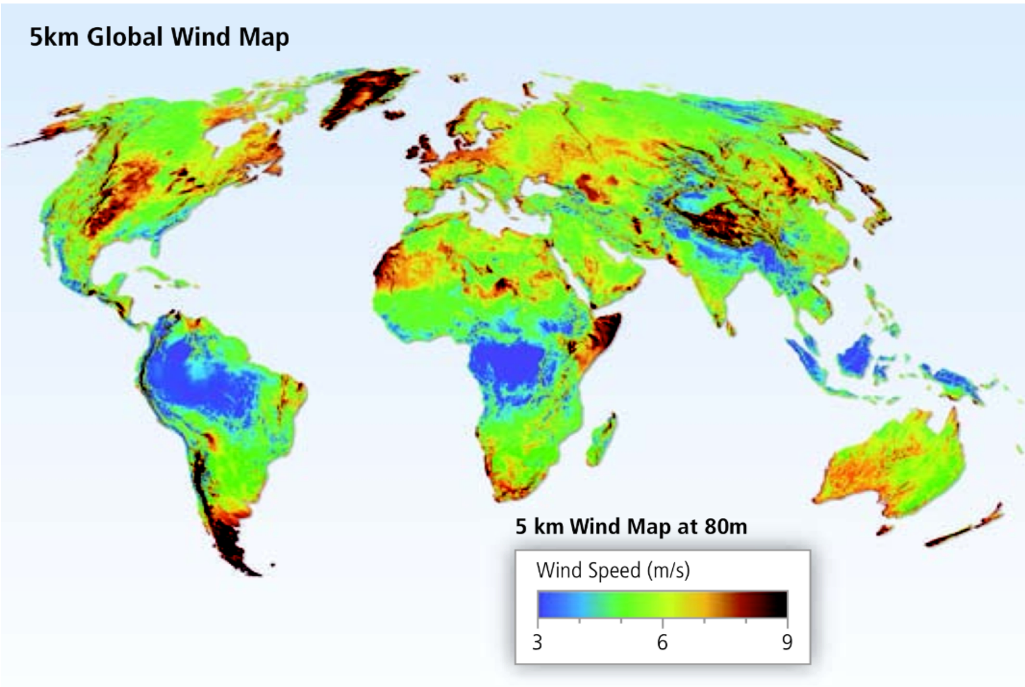

FIGURE 1. Example global wind resource map with 5 km × 5 km resolution (IPCC, 2011).

Figure 1 presents an example global wind resource map with 5 km × 5 km resolution, and offers information to determine the potential wind energy, as well as demonstrates the technical potentials in different regions (IPCC, 2011). Additionally, the wind power is proportional to the density of the air, which means that a wind turbine will produce more energy for the same wind speed at lower altitude area. Moreover, wind energy is proportional to the swept area of the wind turbine or the square of the rotor diameter, as well as the cube of the wind speed. (Kalogirou, 2013.)

3.2 Wind energy characteristics

In this section, the main positive and negative characteristics of wind energy are introduced. The affordability and cleanness are the major advantages of wind energy. Meanwhile, location and weather dependency as well as low levels of predictability are major drawbacks of wind energy. However, the demand of wind energy is still increasing at present.

3.2.1 The affordability and cleanness of wind energy

According to Abbasi and Premalatha in 2013, wind energy is considered as the most popular one of cleanest energy sources, because it has the least adverse environmental impacts and it is more economically affordable compared with other sources of renewable energy. Due to these advantages, wind energy is perceived as the most utilized of all renewable energy sources for electricity generation nowadays if hydropower is excluded from the consideration. (Abbasi & Premalatha, 2013.)

China and The United States were two of the top five countries ranked for cumulative installed wind energy by the end of 2009, the other three countries were Germany, Spain and India (IPCC, 2011). Germany was acting as world leader in producing wind-based power until 2007, and The United States surged ahead in 2008, but only to be overtaken by China in 2010 (figure 2). China is expected to remain the world leader in predictable future due to the plans where another 200 GW power will be produced from wind energy. By 2013, India was ranked as the fifth biggest producer of wind-based power in the world followed by Spain, with an installed capacity of 17.4 GW at that time. (Abbasi & Premalatha, 2013.)

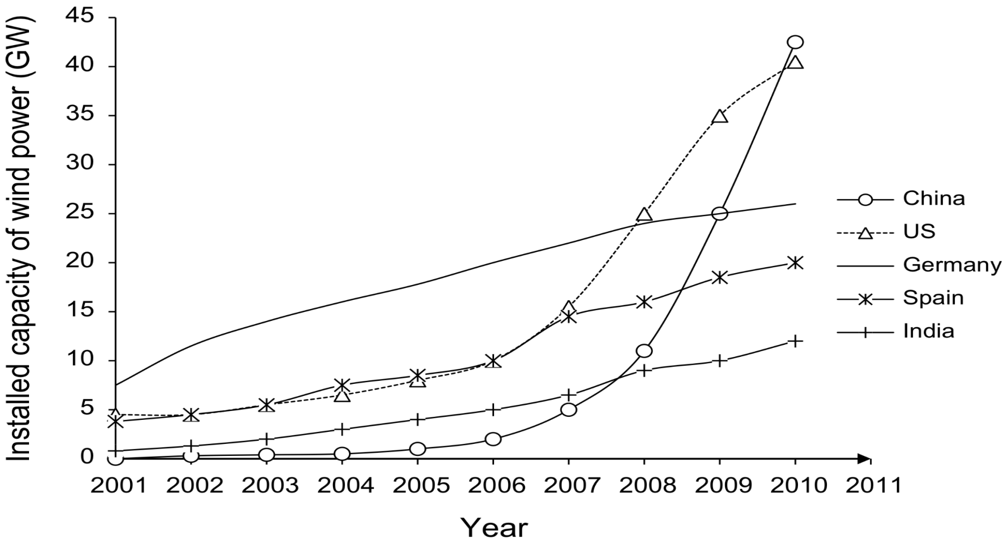

FIGURE 2. Wind power generation by the world's top five wind energy harvesters (Leung &Yang, 2012).

From the global standpoint, the installed wind power capacity was only 14 GW by the end of 1999, and cumulative capacity increased to reach approximately 160 GW by the end of 2009. Most additions have been achieved by onshore wind power plants except 2.1 GW wind power capacity was generated by offshore wind power plants.

From 2000 to 2009, wind energy accounted for a share of 10 % of total capacity additions in the USA and 5 % in China. In 2009, 39 % of total capacity additions were produced by wind energy in the USA and 16 % in China. On the global basis, about 11 % of total global increased electric capacity additions as GW was produced by new wind power plants from 2000 to 2009; in 2009 alone, that figure was likely more than 20 %. (IPCC, 2011.)

Variable electric output, limited output predictability and local dependence are main wind energy characteristics, which raise challenge to electric system planner and operator. However, wind energy has been successfully integrated into existing electric systems. For instance, wind energy was able to meet from 10 % to 20 % of annual electricity demand in four countries (Denmark, Portugal, Spain, Ireland) in 2010. (IPCC, 2011.)

However, the above-mentioned figures are only impressive when we compare wind energy with other renewable energy sources, because the perspective is very different at the overall global energy scenario. According to the IPCC statistics in 2011 (IPCC, 2011), wind energy met only approximately 0.2 % to the total global energy demand by the end of 2009, and 1.8 % of all the world's electricity was generated by wind energy. But the whole picture will change soon because of the urgency to control global warming by replacing coal-based and other fossil fuel-based energy generation with renewable energy sources. Therefore, strong initiatives across the world have enhanced the development and utilization of wind-based power for electricity generation, because wind energy is the most affordable and most clean of all other known renewable energy sources at present. (Abbasi & Premalatha, 2013.)

3.2.2 Usability and reliability of wind energy

Several important characteristics of wind energy must be taken into consideration in electric system planning and operation, in order to ensure the reliable and economical operation of the electric power system. Wind energy is location dependent energy, and the costs of implementing and operating wind power plants depend on location. For instance, the transmission investments are needed for bringing wind energy from higher-quality wind resource areas to electricity demand areas, because usually the higher-quality wind resource areas are not situated close to population. The second considered characteristic of wind energy is weather dependency. Thus, the power output of a wind power plant can be very variable. Therefore, the variability of wind power might affect the electric sector planning and electric system reliability. The third characteristic to consider is that wind power output has lower levels of predictability in comparison with other types of power plants due to the variability and uncertainty. (Abbasi & Premalatha, 2013.)

3.2.3 The increasing demand and changing perception of wind energy

The Inter-governmental Panel on Climate Change (IPCC) in its latest reports has expected that wind energy could meet more than 20 % of the world's electricity demand by the year 2050 (IPCC, 2011). In addition, the European Union has set the "20-20-20" targets in 2007 (EU, 2014), where three main key objectives were included:

- A 20 % reduction in EU greenhouse gas emissions from 1990 levels;
- Raising the share of EU energy consumption produced from renewable resources to 20 %;

- A 20 % improvement in the EU's energy efficiency.

The “20-20-20” targets also aim to rely heavily on wind energy for meeting the first and the third of its targets. The U.S. Energy Information Administration (EIA) estimates the global electricity demand to be 8.5 TW by 2050. (IPCC, 2011.)

In the beginning of the 1980’s there were very few wind turbines in the world, and wind energy was thought to be “totally free” from adverse environmental impacts (Abbasi & Abbasi, 2000). As more than 30 years have passed since then, several wind farms have been installed in the world at present. The wind energy based power generation has grown from 2.4 GW in 1990 to approximately 295 GW in 2012, which means that about 120 times more wind-based power were produced as shown in figure 3.

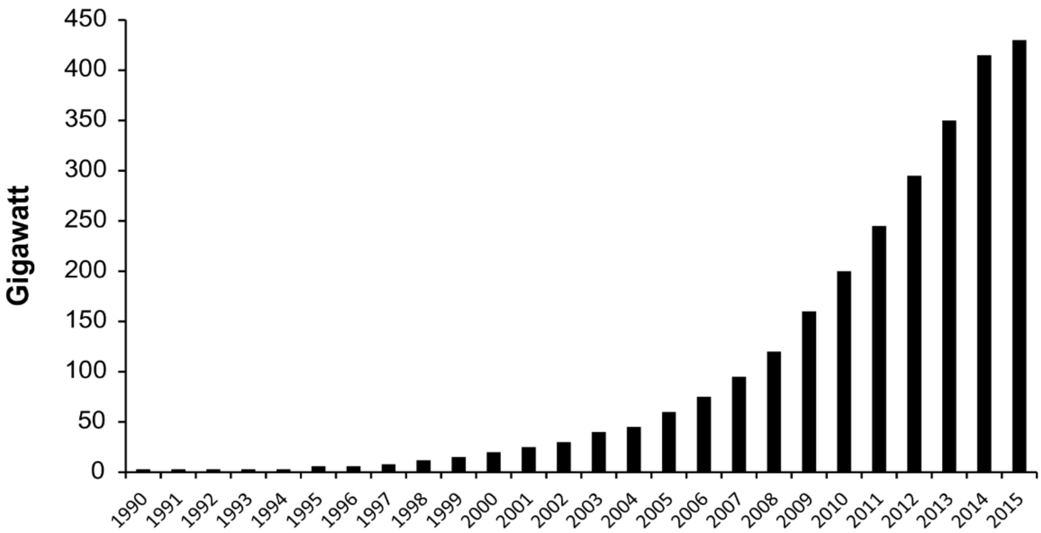

FIGURE 3. Growth in the global wind-power installed capacity up to 2012 and forecasts for 2013-2015 (Abbasi & Premalatha, 2013).

Although only 0.2 % of global energy demand is met by wind power generation now, the detailed and accurate adverse environmental and social impacts still need to be considered. This is because few adverse impacts from wind energy production have come up, and increasing larger size wind farms might be installed at present and in the near future in order to meet the energy demand generated by wind turbines. The increased change in the use of wind power has brought wind power from so called” non-polluting” to “less polluting”. It would be wise to predict and prevent the adverse environmental and social impacts from wind energy production before several thousand GW of power will be generated as demanded. (Abbasi & Premalatha, 2013.)

3.3 Wind turbines and its development

A wind rotor can extract power from the wind because it slows down the wind. The wind speed behind the rotor is lower than in front of the rotor. The types of wind turbines are divided into two main categories, which are the horizontal axis wind turbines (HAWTs) and the vertical axis wind turbines (VAWTs). All particular models of wind turbines gradually developed from one of these categories. Nowadays, HAWTs has taken the dominated position in the market, and numerous designs of wind turbines have been proposed and developed for the purpose of reducing total cost and increasing efficiency. (Kalogirou, 2013.)

3.3.1 Detailed types of wind turbines

HAWT and VAWT are the two major categories of wind turbines. Figure 4 shows the main designs of wind turbines, including HAWTs and VAWTs respectively. Today, the basic system of HAWT starts with a large rotor comprising two, three, or four blades fixed on a horizontal shaft at the top of tower. In figure 4 (a), the single-bladed machine was not listed, which offers the lowest cost and the lowest weight solution but must balance the weight during installation process. The most feasible design offering the lowest cost is the two-bladed machine, but the drawback is the high level of noise produced. Four-bladed machines are designed with good rotor balance, but are heavier and less cost-effective. (Sorensen, 2009.) Nowadays, most of turbines are manufactured with three blades, due to not very high cost and smoother rotational operation compared to various types. US farm or California-type wind turbine was used for water pumping years ago successfully. (Kalogirou, 2013.)

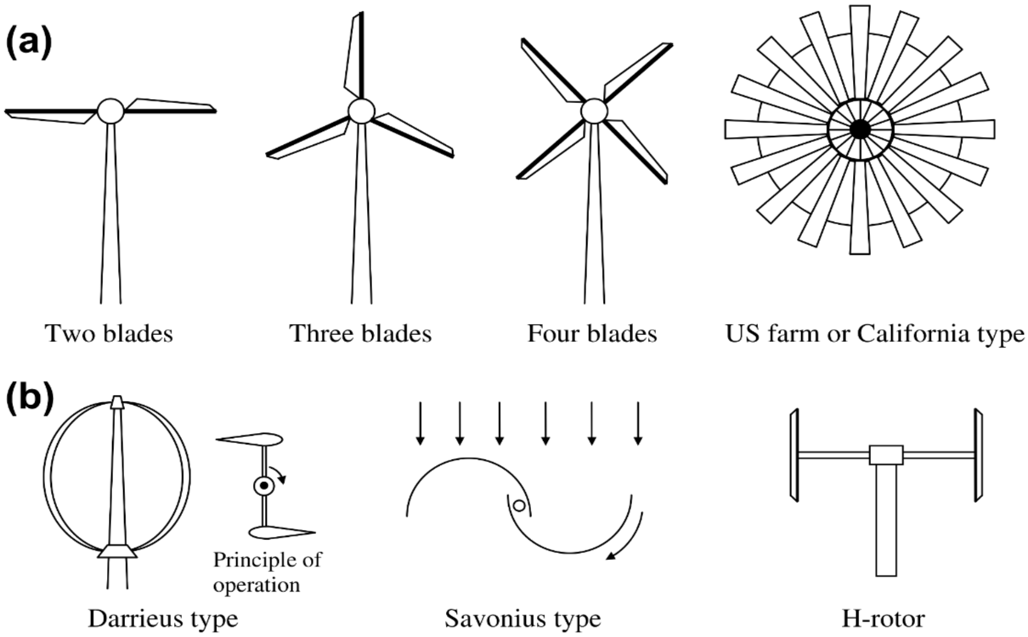

FIGURE 4. Main types of wind turbines. (a) Horizontal axis wind turbines. (b) Vertical axis wind turbines. (Kalogirou, 2013.)

Alternatively, the weight of VAWT is supported by a ground level bearing. In addition, both gearbox and generator can be supported at ground level, which makes maintenance process easier compared to HAWT. Another advantage of VAWT is that the turbine can be operated no matter which direction wind blows from, thus, no pointing mechanism is required to align with wind direction. The most notable designs of VAWT are the Darrieus, the Savonius and the H-rotor machine as shown in figure 4 (b). VAWTs are good for pumping water and other high torque low-speed applications and are not usually connected to the electric power grid. (Kalogirou, 2013.)

3.3.2 Structure of horizontal axis wind turbines

HAWTs are more applicable for electricity generation in comparison with VAWTs. Thus, more details about HAWT are presented in this section. Usually, a complete horizontal axis modern wind turbine is comprised with hub, rotor blades, tower, as well as nacelle with gearbox and generator (as shown in figure 5).

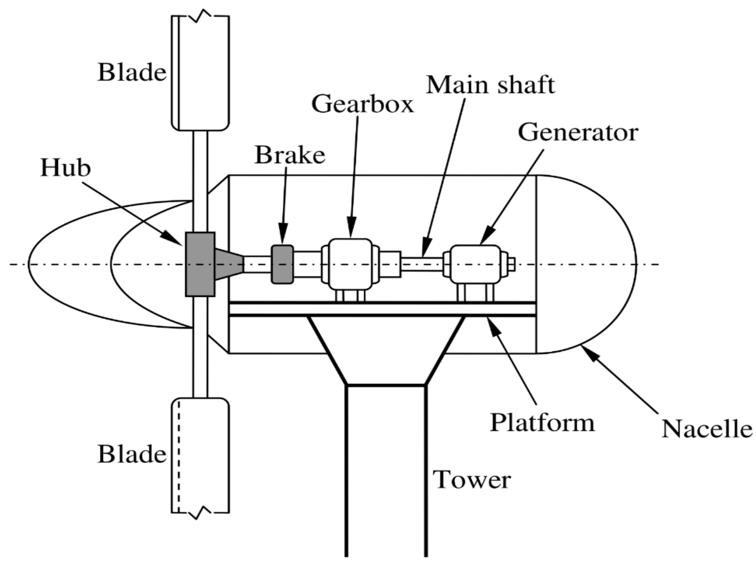

FIGURE 5. Components of horizontal axis wind turbine (Kalogirou, 2013).

The slow rotation of the shaft of an HAWT is normally increased with a gearbox and passed to the generator. Gearbox and generator are attached directly to the turbine shaft via a braking system as shown in figure 5. The electricity generated by the generator is taken with cables through the tower to a substation and ultimately to the grid. The rotor, gearbox and generator are attached on a platform which is able to rotate a vertical axis so that the rotor shaft is perpendicular to the wind direction. (Kalogirou, 2013.)

Modern wind turbines rotate at speeds between 5-20 rpm (revolutions per minute, means the measurement of the frequency of a rotation) whereas generators operate between 800-3000 rpm. Thus, it is necessary to use a speed-up gearbox in order to increase the speed to the required level. Moreover, a speed-up gearbox not only withstands the rotational speed from the rotor, but also the bending moment created due to the variability of the wind with height, as well as the force created by the generator trying to synchronize its speed with the grid frequency. (Kalogirou, 2013.)

A system called direct-drive system has been developed in which the rotor blade is connected directly to the generator, because gearboxes require greasing and frequent maintenance that has to be done at the hub level. Otherwise, the gearbox would become the component of the system which most likely creates problems or fails. Another design gaining ground at present is the use of a variable-speed generator, because it would reduce the mechanical stresses on the gearbox and increase the overall efficiency of a wind turbine. (Kalogirou, 2013.)

Tower house is the place for wires transmitting the generated electricity, and installing the control and isolation system. Additionally, an elevator and stairs can be built in tower house for maintenance of nacelle. Nowadays, the cylindrical metal design of tower dominates the market. Towers are fixed on a large diameter underground concrete base, thus, substantial excavation during the construction phase is required. The diameter of the tower depends on the rotor diameter and tower height, both depending on the desired capacity of the turbine and wind speed. (Kalogirou, 2013.)

3.3.3 Development of wind turbines

The challenge for wind energy industry is to design cost effective turbines and power plants in order to perform the conversion, where generating electricity from the wind requires that the kinetic energy of moving air is converted to mechanical and electrical energy afterwards (IPCC, 2011). Therefore, the combined power coefficient is the product of the mechanical efficiency, the electrical efficiency, and the aerodynamic efficiency.

All three efficiencies can be influenced by wind speed and the wind power. Theoretically, the maximum aerodynamic conversion efficiency of wind turbines from wind to mechanical power is 59 % in accordance with the Betz law (Kalogirou, 2013), which means the maximum wind energy that can be converted into electrical energy by the wind turbine is 59 % if there are no mechanical or electrical loss. However, the basic properties of even the most efficient modern aero foil sections limit the peak achievable efficiency of medium and large size wind turbines to be around 48 %. In practice, the need to economize on blade costs leads to the construction of slender bladed. The slender-bladed machines are fast running wind turbines with peak efficiencies a little lower than the optimum, which is approximately 45 %. The average efficiency of most turbines is about half of this figure, because of the need to shut down the wind turbine in low or high wind speeds and the need to control the power once the rated level is reached. Furthermore, generator loss causes the reduction of the average efficiency, as well as the fact that the machine does not always work in its optimum working point. (Beurskens & Garrad, 1996.)

Due to the proportional correlation between generated wind energy and the swept area of the wind turbine or the square of the rotor diameter, the average wind turbine size has grown significantly from 1980's to 2010. As it can be seen from figure 6, the largest units today can produce 7.5 MW with rotor diameter of 170 m. It is predicted that machines with diameters of 250 m capable of producing 20 MW, will be produced in the next following years.

The main reasons for the continual increase in turbine size is to minimize the generation cost of wind energy; to reduce material usage; to increase component and system reliability; to increase electricity production; to reduce investment costs per unit of capacity; to reduce maintenance cost per unit of capacity (EWEA, 2009). On the other hand, increased turbine size may eventually be limited by not only logistical constraints of transporting the large size components of wind turbines by road, but also the constraints of engineering and material usage (IPCC, 2011).

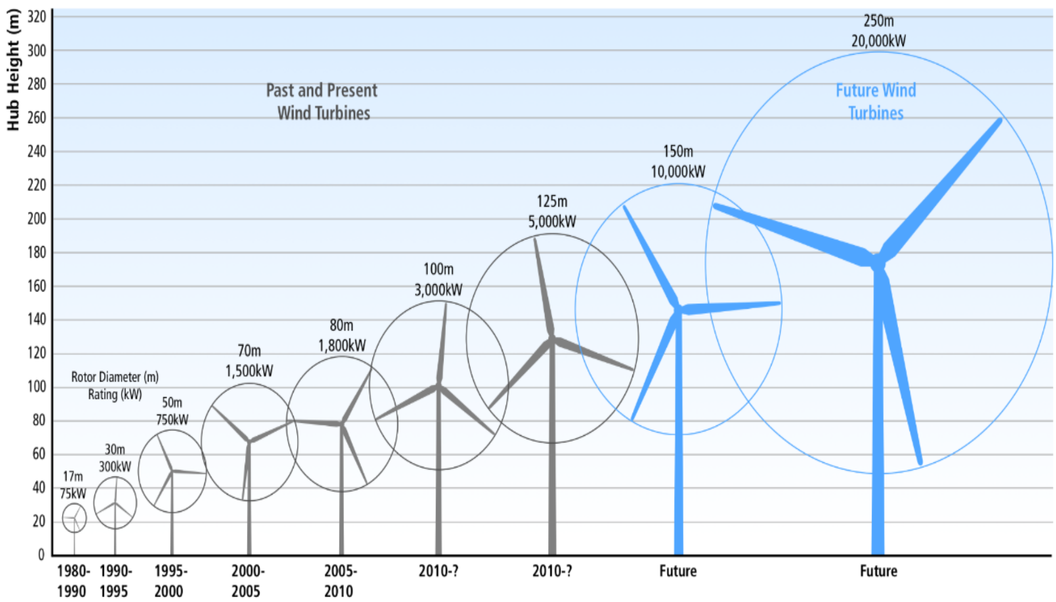

FIGURE 6. Growth in size of commercial wind turbines (IPCC, 2011).

3.3.4 Calculation of power characteristics of wind turbines

In order to well understand this section, it is necessary to introduce several definitions related to wind power characteristics and the calculation of working efficiency of a real wind turbine, for instance, wind power density, Betz limit and wind power coefficient etc. Wind power density means the potential wind power of a specified area. Betz limit states the maximum power that can be obtained from a wind turbine, and the coefficient value of maximum power at Betz limit is 0.593, which is a constant number. Wind power coefficient means the sum of mechanical efficiency, electrical efficiency and aerodynamic efficiency. (Kalogirou, 2013.)

The most convenient quantity for the evaluation of the wind potential of a site is the power of wind. The power density is equal to the wind power divided by the area. As it was said, the factors affecting wind power can be seen in Section 3.1 Wind resource. The calculating equation of wind power density is shown below as formula 1. (Kalogirou, 2013.)

$$E = \frac{1}{2}\rho V^3 \tag{1}$$

Where

E = wind power density

ρ = air density at certain temperature

V = wind speed

With a time series which includes the wind speed and air density, the wind power can be estimated by using the following formula 2. Of course, the calculation of wind power must consider the characteristics of wind turbine. (Kalogirou, 2013.)

$$p = \frac{1}{2}\rho V^3 A_R \eta \tag{2}$$

Where

P = wind power,

ρ = air density at certain temperature

V = wind speed

A_R = rotor area of the wind turbine

η = combined power coefficient (including mechanical efficiency, electrical efficiency and aerodynamic efficiency)

The thrust value means the force when undisturbed speed of an axial air flow ($V\infty$) is passing through the rotor area of a turbine. Axial interference factor (α) can be obtained through the equation V_R= (1- α) $V\infty$, where V_R means the axial velocity in the rotor plane. By using the following formula 3, the value of thrust can be obtained. (Kalogirou, 2013.)

$$T = 2\rho A_R V_\infty^2 \alpha(1-\alpha) \tag{3}$$

Where

T = thrust force

α = constant number 1/3 (which is axial interference factor).

The maximum power of a real wind turbine can be obtained from the following formula 4 (Kalogirou, 2013):

$$P_{real} = P_{Betz}\frac{C_{P,real}}{C_{P,Betz}} \tag{4}$$

Where

P_{real} = maximum power of a real wind turbine

P_{Betz} = maximum power of wind turbine at Betz limit

$C_{P,real}$ = maximum power of coefficient of a real turbine

$C_{P,Betz}$ = power coefficient of wind turbine at Betz limit.

3.3.5 Offshore wind turbines and onshore wind farm

According to the different installed locations, wind turbines can be grouped to offshore wind turbines and onshore wind turbines. In case the village is near sea or shoreline, the offshore wind turbines can be used to generate energy. Generally, it is more expensive to build offshore wind turbines compared to onshore wind turbines, however, the associated cost is offset by the higher annual energy generation due to the higher wind speed. The most feasible solutions to install wind turbines are in sites where the water is relatively shallow and which are at a distance of about 25 km from the shoreline, even though nowadays there are solutions for sites where the water is deep. (Kalogirou, 2013.)

The major economic drawback of offshore wind turbines is the expensive cost. Depending on the distance from the shoreline and the depth of seawater, the additional cost can be between 40 % and 100 % in comparison with onshore wind turbines installation cost, as well as the higher grid connection cost. Moreover, the maintenance cost is increasing, because boat transportation to each wind turbine is required based on the normal standard. As mentioned above, the higher wind speeds available and the stability of the resource could offset the high costs due to the higher electrical energy output. (Kalogirou, 2013.) The global offshore wind energy resource is estimated to be approximate 37 500 TW per hour (Leutz et al., 2002).

Onshore wind farms are a number of wind turbines clustered together, and they are usually installed in low population or offshore area in order to reduce the reaction of public who are opposed to the development of wind energy. Due to the installed location, the extra costs are created, for instance, the cost for transferring the electrical energy to the populated area.

Wind farms require a large area to install a number of wind turbines, so as to make sure they will have 5-10 rotor diameter space in between wind turbines in order to avoid wind interference effects. In addition, a substation will be normally required to raise the voltage to the value of the distribution grid voltage for the connection of the wind turbines of a wind farm to the grid. (Kalogirou, 2013.)

3.4 Environmental impacts of wind turbines

The major environmental benefits of wind energy result from replacing electricity generation from fossil fuel-based power plants burning gas, oil and coal, due to no GHG emissions or other air pollutants emitted directly from operation of wind turbines. However, wind energy still produces indirect environmental impacts from manufacturing, transport, installation, operation and decommission process of wind turbines. Life-cycle assessment has been used to analyze these impacts and to determine the lifecycle GHG emissions per unit of wind electricity generated. (IPCC, 2011.)

According to World Nuclear Association in 2010, the lifecycle GHG emission intensity of wind energy was estimated about 26 g CO_2/kWh, as shown in figure 7. In addition, figure 7 shows the comparison of lifecycle GHG emission intensity among electricity generation methods, including traditional fossil fuels, as well as other type of renewable energy systems. (World nuclear association, 2010.)

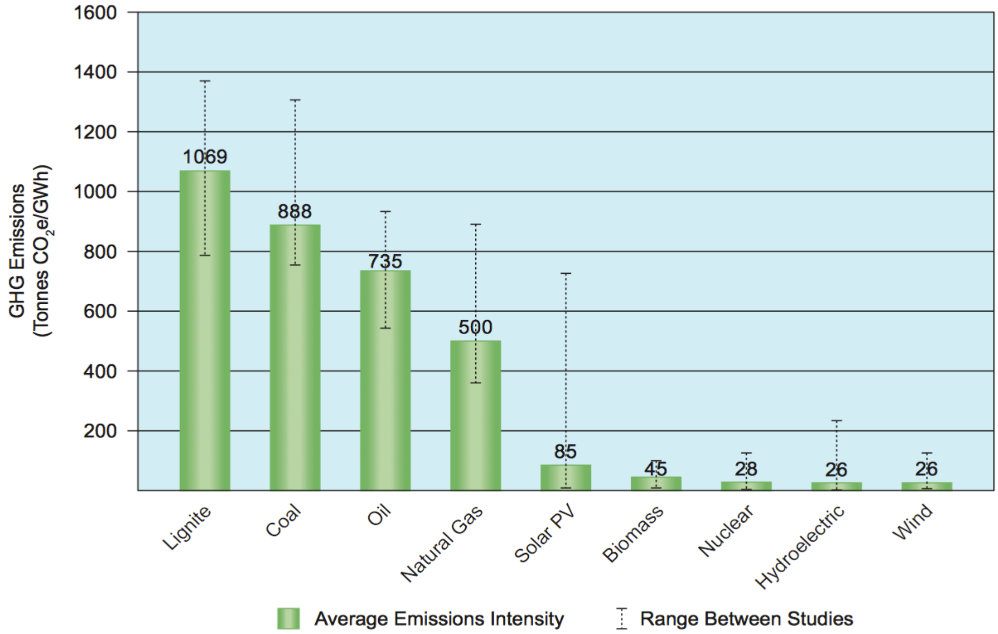

FIGURE 7. Lifecycle GHG emission intensity of electricity generation methods (World nuclear association, 2010).

As it can be seen, coal burning power plant as one of fossil fuel burning power plants has the highest GHG emission intensity on a lifecycle basis, followed by oil and natural gas burning power plants. Wind energy as one of the renewable energy systems has the lowest GHG emission intensity on a lifecycle basis, and the value is about 26 g CO_2/kWh. (World nuclear association, 2010.)

According to figure 7 (World nuclear association, 2010), the lifecycle GHG emission intensity of a wind power plant accounts for a share of about

- 3 % of emission intensity of a coal burning power plant
- 3.5 % emission intensity of an oil burning power plant
- 5.2 % emission intensity of a natural gas burning power plant.

In addition to the estimation made by World Nuclear Association in 2010, IPCC estimated that the energy consumed and GHG emissions produced from lifecycle of wind turbines (including manufacture, transport, installation, operation and decommissioning process) were small in comparison with the amount of generated energy and avoided GHG emissions over the lifetime of wind turbines in 2011: the GHG emission intensity of wind energy was estimated between 8-20 g CO_2/kWh in most cases, while emission payback times were between 3.4-8.5 months (IPCC, 2011). Globally, it has been estimated that about 160 GW of wind power capacity installed by the end of

2009 could produce 340 TWh/year of electricity and save more than 0.2 Gt CO_2 /year (GWEC, 2010).

Wind energy requires little consumption of water and produces little waste compared to other energy generation sources, and enhances fuel saving. In the early stage, wind energy was used for marine propulsion, grinding of grain and water pumping. At present, using wind energy to pump water is still an important mean to serve domestic and agricultural needs, especially in remote areas. With the development of wind energy, the mechanical and electrical use of wind energy can also be applied for other things, for instance, water purification and desalination. These technology systems may yield fuel savings of up to 50 % according to technology and wind conditions. (O'Rourke, 2006.) When wind turbines are used to operate as part of an interconnected grid for which the dominant share of energy is produced by operators burning traditional fossil fuels (coal, oil, natural gas), wind energy generation replaces fossil fuel use at a rate around 1:1. In other words, the amount of "saved" and " avoided" fossil fuels by using wind power plants may be estimated about 90-95 % of the fuel that is required to produce the same amount of electricity at fossil-fuel power plants. (Komanoff, 2009.) Furthermore, the utilization and development of wind energy will have positive indirect influence to climate change, human health, material damages and agriculture losses (IPCC, 2011).

3.5 Ecological impacts of wind turbines

Similar to environmental impacts, ecological impacts of wind energy are necessary to consider when assessing and evaluating wind energy. For onshore wind power plants, ecological considerations include population level consequence of birds and bats, and indirect habitat and ecosystem impacts. For offshore wind power plants, impacts on fisheries, benthic resources, and marine life are generally more considered. Finally, the possible impacts of wind energy on the local climate should be assessed as well. (IPCC, 2011.)

3.5.1 Impacts on bird and bat

The death of bird and bat through collision with wind turbines is one of the most publicized ecological concerns caused by the operation of wind power plants. Thus, the decline in the population of bird and bat leads to the concerns about the effects of wind energy on vulnerable species. Many factors of wind power plants could influence the avian fatality rates, for instance, region, site characteristics, season, weather, turbine size, turbine types, and turbine working period.

According to the survey which is done by the US National Research Council (NRC) in early 2007, found bird mortality estimates that range from 0.95 to 11.67/MW/year. Songbirds as the most abundant bird group in the terrestrial ecosystems have relatively higher fatality rate compared to raptors. However, raptor fatalities still need to be considered as a great concern because their population is relative small. (NRC, 2007.) As offshore wind energy has increased, concerns about impacts on seabirds have been raised (Garthe & Huppop, 2004).

Although bat fatalities have not been researched as extensively as bird fatalities, several surveys are done to report the observed bat fatalities (IPCC, 2011). The NRC reported observed bat fatalities rate ranging from 0.8 to 41.1/MW/year in 2007 (NRC, 2007). Also another survey done by Arnett in 2008 reported bat fatalities rate ranging from 0.2- 53.3/MW/year (Arnett et al., 2008). Still, the impact of wind power plants on bat population is a great concern, due to the low reproduction rates and current population of bats (Horn et al., 2008). Additionally, other human activities cause higher bat and bird fatalities rate than wind power plants does, for instance, vehicles, transmission lines, communication towers, pollution and other contaminants (NRC, 2007).

3.5.2 Habitat and ecosystem modification

Compared to impacts of bird and bat collision fatalities, the habitat and ecosystem modification impacts of wind power plants remain unclear. Onshore wind turbines are usually installed in agricultural landscapes or on brown-field sites. The nature of impacts caused by wind power plants partly depends on the local ecosystem status where the turbines are installed. According to the report published by the NRC in 2007, the operation of wind turbines would cause impacts on flora and fauna. If the wind turbines are installed in undisturbed forests, the development may lead to habitat destruction and fragmentation for forest-dependent species, because of forest clearing for assess roads, turbine foundations and power transmission lines. (NRC, 2007.)

The impacts of wind power plants on marine life need to be considered for assessing the ecological impacts of offshore wind turbines. The magnitude of impacts depends on the installation, operation and decommissions phase, as well as specific site conditions. Potential adverse impacts caused by offshore wind turbines include underwater sounds and vibrations, electromagnetic fields, physical disruption and the introducing of alien species. (IPCC, 2011.)

3.5.3 Impacts of wind power plants on local climate

Wind power plants extract momentum from the air flow, therefore, wind speed becomes slower behind turbines and introducing turbulence across a range of length scales would increase vertical mixing. These processes are called as “wind turbine wake” (Barthelmie et al., 2004). Wind turbine wake increases vertical mixing of the near-surface layer and might increase the atmosphere-surface exchange of heat and water vapor. These potential effects could also influence local rainfall pattern, radiation, clouds, wind direction and other climate variations. However, the impacts of wind power plants on local climate remain uncertain, and it should be recognized that wind turbines are not the only structures that potentially affect local climate variables. (Sta.Maria& Jacobson, 2009.)

3.6 Impacts on human well-being and activities

In addition to ecological impacts, the development of wind energy influences human well-being and activities in many ways. In this section, the impacts of wind power plants on human health and safety are addressed, for instance, noise, flicker. In addition, visual impacts and influence on land and marine usage are presented in this section. (IPCC, 2011.)

3.6.1 Noise and health

Noise is the most prominent kind of nuisance effects related to wind energy development, especially for those living within close range. Annoyance from wind turbine sound can impact sleep patterns and well-being. Concerns about noise emissions may be raised when hub height wind speeds are high meanwhile ground-level speeds are low. Significant efforts have been done so that sound levels emitted by wind turbines can be reduced, for instance, mechanical sounds from modern turbines have been substantially reduced. In addition, reducing blade speed could easily reduce the aero-acoustic noise, which is the dominant concern nowadays. Furthermore, the environmental regulations and predictive models used to manage these impacts have been improved. Despite these efforts, concerns about noise emission still are obstacles to wind energy deployment in some areas. (IPCC, 2011.)

3.6.2 Visual impacts

As shown in figure 6 in Section 3.3.3 Development of wind turbines, wind turbine size has grown bigger and bigger over past few decades in order to increase wind power output and to meet wind energy demand. Moreover, grown size of wind power plants makes turbines and associated transmission infrastructure more visible (IPCC, 2011). As consequence, visual impacts are one of top concerns of communities considering wind power plants in addition to noise and other health concerns, especially to those who are living near wind farms or offshore wind turbines. Most people would like to visit wind farms, but not install wind turbines in their “back yard”. However, due to increased number and geographic spread, wind power plants are being located in a wide diversity of landscapes. Using turbines of similar size and shape can be recommended to minimize visual intrusion, as well as using light-colored paints and burying connection cabling. (IPCC, 2011.)

3.6.3 Land and marine usage

Installation of wind turbines requires a large area in order to avoid wind interference effects between them. Onshore wind turbines and associated infrastructure specifically disturb the land footprint, for instance, roads accessing for the installation of wind turbines. However, it allows to continue agricultural activities and other certain activities within area which range from 2 % to 5 % of the total area encompassed by a wind turbine. Some other types of activities might be precluded from the area, for instance, airport building and radar installations. (IPCC, 2011.)

Generally, wind turbines can interfere with detection of signals through reflection and blockage of electromagnetic waves and creation of large reflected radar returns. Thus, it is necessary to consider the possible impacts of wind power plants on shipping, fishing, aviation, communication and radar systems, and these possible impacts depend on the placement of wind power plants. The interference of wind power plants with aviation and shipping can be minimized to lowest by avoiding airplane-landing corridors and shipping routes. (IPCC, 2011.)

3.7 Minimizing social and environmental concerns

Involving the local community in the planning and establishing process has been shown to improve outcomes of wind energy projects (Loring, 2007). For instance, allowing the community to take part in planning and decision making process of wind power plant and turbine location, and improving education by organizing visits to existing wind power plants. In addition, benefit-sharing mechanism is an effective solution to improve public attitudes towards wind energy development. (Jone& Eiser, 2009.) Proper planning for offshore wind turbines and onshore wind farm can help to minimize negative environmental and social impacts. Through careful placement of wind power plants and proactive governmental planning for wind energy deployment, the habitat fragmentation and ecological impacts can be minimized. (IPCC, 2011.)

3.8 Economic factors of wind energy

As it was said, the economics of wind energy system depend on available wind speed and the stability of wind resource. According to the Chapter 13.3.2 Power characteristics of wind turbines in the book called Solar Energy Engineering-Processes and Systems (Kalogirou, 2013), the efficiency of wind turbines typically reaches a maximum value at a wind speed of 7-9 m/s, and the normal lifetime of wind turbine is 20-25 years. Thus, the selection of a suitable site is very important to the economics of wind energy generation. Furthermore, the type of terrain, the distance from existing electricity grid, the availability of road and the infrastructure of selected location are other important factors related to the cost. With the modern wind turbines, the minimum speeds which are considered economically exploitable are 5-5.5 m/s for onshore and 6.5 m/s for offshore shore sites (Sorensen, 2009).

Costs of wind turbine installation usually include as shown in following (Kalogirou, 2013):

- Turbines installation cost, including foundation cost, transportation cost and cranes cost;
- Road construction cost;
- Underground cabling within the wind park;
- Cost of control and monitoring;
- Testing and commissioning cost;
- Maintenance cost;
- Administrative, financing and legal costs.

Table 2 shows the investment cost distribution for both onshore and offshore wind power plants. The other investment costs of wind power plants depend on the size of wind turbines and amount of energy produced, including insurance, taxes, management fee, forecasting service, administrative cost, and land leases. In addition, operation and maintenance costs are not fixed because they depend on the location, turbine type and age, the availability of a local serving infrastructure, and other factors. (EWEA, 2009.) In 2011, IPCC assumed that the average operation and maintenance costs over the life of onshore and offshore plants were approximately 1.6 US $cents_{2005}$ /kWh and 3 US $cents_{2005}$ /kWh, respectively (IPCC, 2011).

TABLE 2. Investment cost distribution for onshore and offshore wind power plants (EWEA, 2009).

Cost Component	Onshore (%)	Offshore (%)
Turbine	71-76	37-49
Grid connection	10-12	21-23
Civil works	5-9	21-25
Other investment costs	7-8	9-15

Wind energy is known as an intermittent resource, such as solar energy. However, wind energy still represents a certain capacity credit, although the factor is 2-3 times lower than the value for nuclear and fossil fuel-fired plants. Wind energy technology has developed significantly over the last few decades, lowered capital costs to as low as 1000-1350 €/kW for onshore installations and 1500-2000 €/kW for offshore installations, depending on the specific condition of installed sites. Therefore, wind energy is economical at locations with good wind resource. (Kalogirou, 2013.) Compared to the investment costs of wind power plants on the basis of calculation done by IEA, most coal burning power plants have construction costs between 1000-1500 USD/kW (727-1090 €/kW), and the construction costs of gas-fired power plants could be ranged between 400-800 USD/kW (290-581 €/kW) (IEA, unknown). The currency change from USD to euro is done today.

Overall, wind energy can compete with energy from traditional resources only under suitable wind and grid situation. Decreasing cost will extend the market potential for wind turbine systems in the future by reducing the investment, as well as developing the wind energy technology and exploiting the best available wind sites. (Kalogirou, 2013.)

4 CASE STUDY- FELDHEIM VILLAGE

In this chapter, brief background information and climate conditions of Feldheim village are shortly introduced. On the basis of geographical peculiarities, the analyses of general energetic facts in Feldheim are emphasized, as well as information of utilized renewable technologies. As a local success story, the establishment of energy independent village in Feldheim has brought positive environmental and socio-economic impacts to society. Thus, the economic factors of installed renewable energy technologies and other benefits are also shortly presented.

4.1 Background

Nowadays, there are increasing discussions and suggestions for shifting towards 100 % renewable energy and it is very vital to follow the trends to sustainable development. The German Federal Government has committed to a goal of 80 % of electricity being generated by renewable energy by 2050. (Lund, 2009.) Thus, Germany's energy system is in transition, and this transition is widely recognized as a leading approach for renewable energy development at local, regional and national levels. Germany is confident for the security and affordability of energy transition. For these reasons, many municipalities are contributing to Germany's national renewable energy targets, and Feldheim village is a typical one of them. (SRU, 2011.) Figure 8 shows share of renewable energy in Germany until 2012.

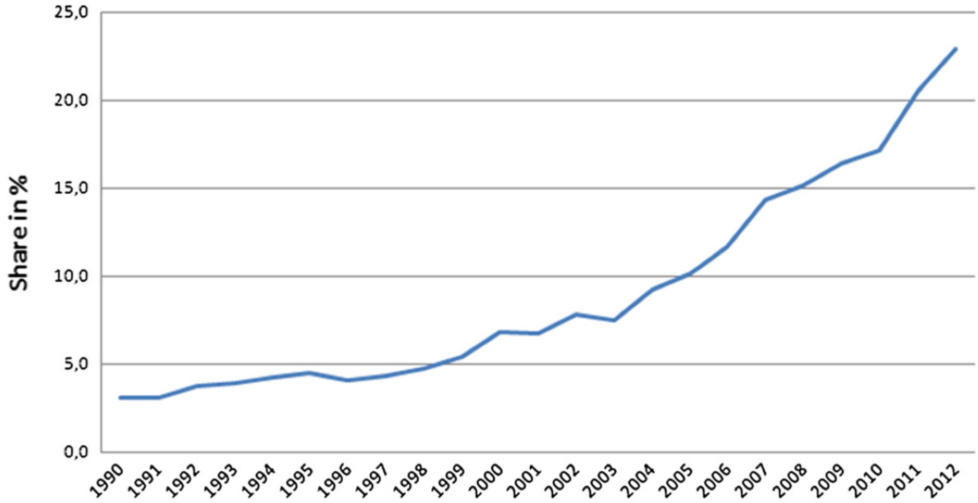

FIGURE 8. Share of renewable energy in Germany (Busch& McCormick, 2014).

4.2 Brief introduction of Feldheim village

Feldheim is located in the municipality of Treuenbrietzen, about 83 kilometers south-west of the German capital−Berlin (FNEFF, 2012). Figure 9 shows the location of Feldheim village in Germany. Feldheim has great importance in the whole energy system in Germany, because this village is the first settlement in Germany that has achieved energy self-sufficiency. In addition, Feldheim is the only town in Germany which started its own energy grid and got all electricity and heat through the utilization of local renewable sources. Nowadays, Feldheim is the home of 221 citizens, and the main constructions there are residential homes. Also, farms, some light industries and communal buildings are located in Feldheim. (Busch& McCormick, 2014).

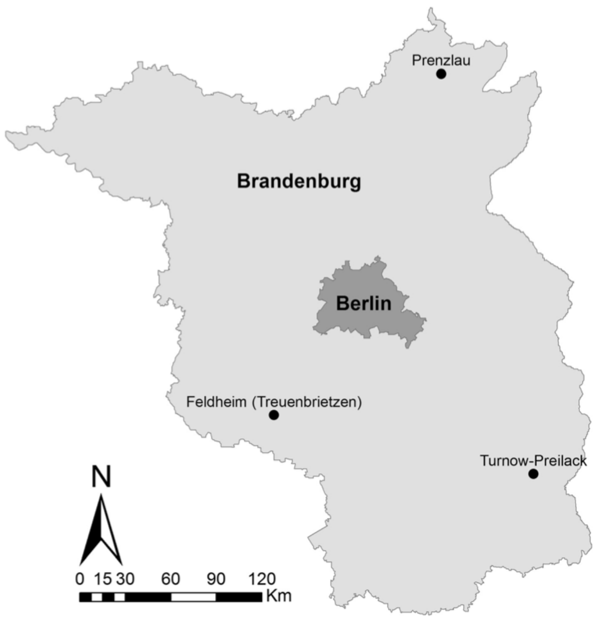

FIGURE 9. Location of Feldheim village in Germany (Busch &McCormick, 2014).

The local company, called Feldheim Energie, supplies electricity and heat for warm water and heating purposes to almost all households. In terms of electricity, the wind farm produces total annual output 74 MW; the biogas plant produces 500 kW; the solar farm produces 2.3 MW, and extra electricity will be supplied to national grid. (FNEFF, 2012.) What makes Feldheim so successful and special is not only the efficient installed renewable energy technologies, but also the grids of the village belong to a local company. In addition, this local company is owned by the municipality, villagers of Feldheim and the companies and organizations involved in the local energy transition. (Busch &McCormick, 2014.)

4.3 Geographical peculiarities

In order to have full view of energy consumption in Feldheim, it is necessary to have analysis of village's geographical condition and the prevailing climate scheme. This was also prerequisite for considering what type of renewable energy technology would be the most efficient to install for sustainable development and for electricity and heat supply in Feldheim. Especially solar energy and wind energy really rely on geographical factors. The analysis of peculiarities in Feldheim gives information about whether the similar energy self-sufficient eco-village can be built elsewhere. The limitations are great factors to take into account in the planning stage of energy independent village projects.

In Feldheim, the average temperature in winter (December-February) is approximately from -2 °C to +4 °C, in spring (March-April) from +2 °C to +11°C, in summer (May-September) from +12 °C to +22°C, and in autumn (October-November) from +3 °C to +10 °C. (World weather online, 2014.) More details of average temperature in Feldheim can be found in figure 10. As it can be seen, energy supply for warm water and heating is needed for the whole year, especially during winter and spring. Figure 11 shows the annual average precipitation amount in Feldheim, which is approximately 50 mm/month. Therefore, Feldheim can be assumed as a suitable land for developing bioenergy due to the annual average temperature and annual precipitation that suit for farming and agricultural purposes.

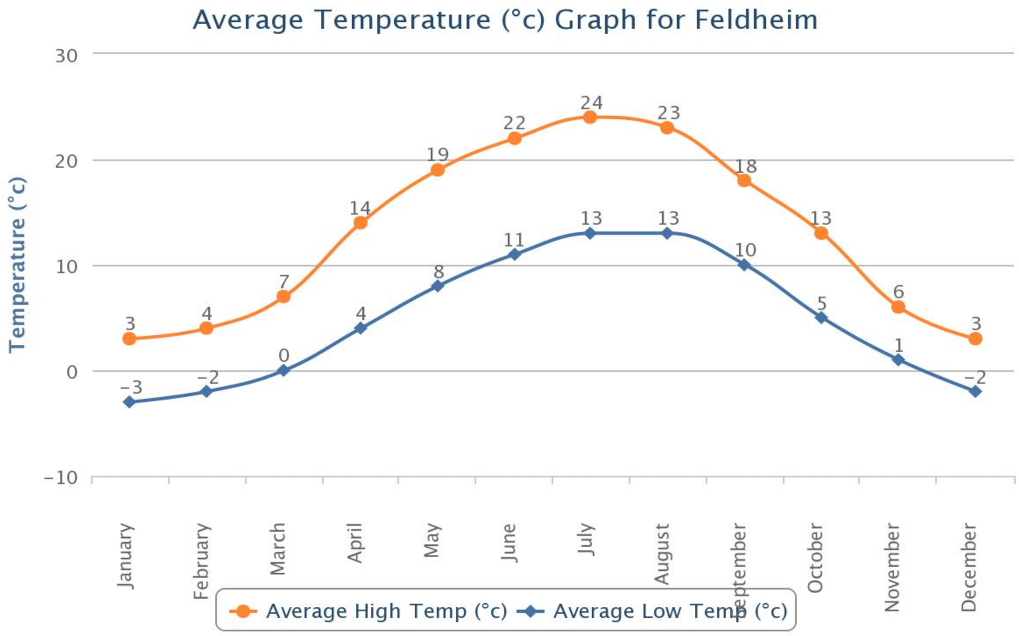

FIGURE 10. Average temperature graph for Feldheim (World weather online, 2014).

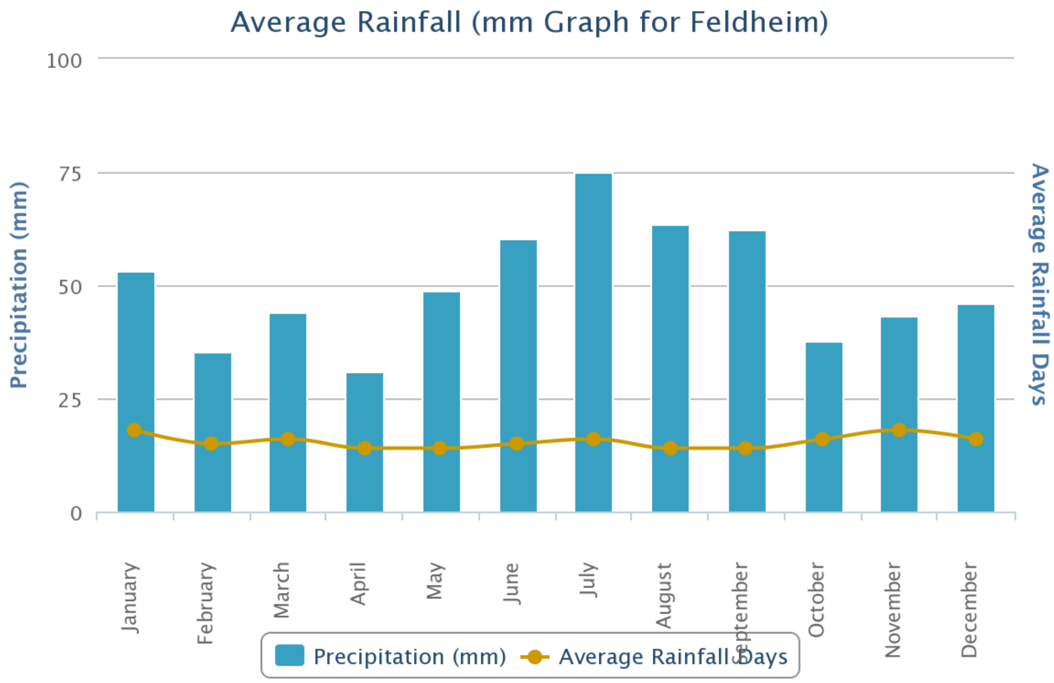

FIGURE 11. Average annual rainfall in Feldheim (World weather online, 2014).

Furthermore, solar activity is a significant factor which influences the efficiency of solar equipment, total energy output by solar technologies, and the availability for installing solar energy technologies. The analysis of solar activity plays an important role in the planning and decision making process of solar energy installation. In figure

12, the red mark represents Feldheim region and gives idea of annual irradiation intensity. According to the data offered by SolarGIS in 2011, the annual irradiation intensity in Feldheim was about 1100-1200 kWh/m^2 (SolarGIS, 2011).

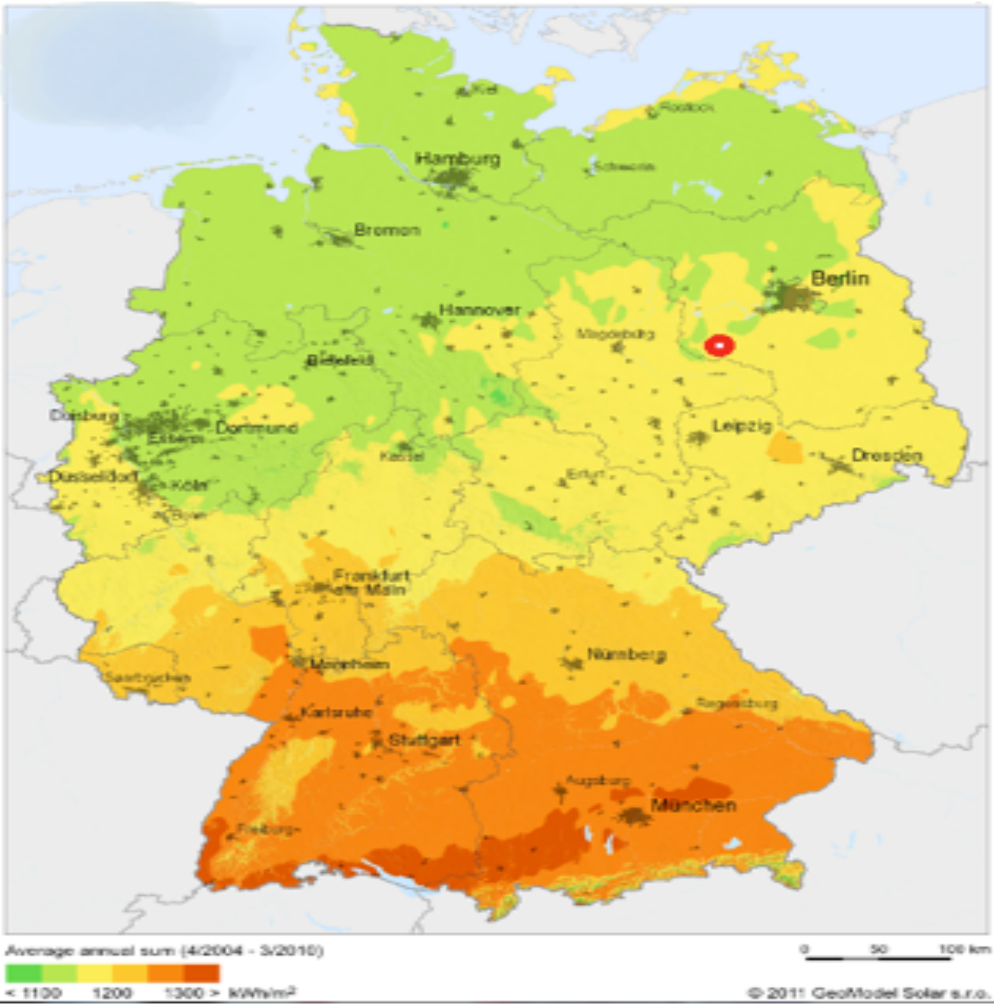

FIGURE 12. Irradiation intensity in Germany in 2011(SolarGIS, 2011).

Wind velocity in Feldheim determines the total power output of 43 wind turbines installed in Feldheim. As discussed in Section 3.8 Economic factors of wind energy, the efficiency of wind turbines typically reaches a maximum value at a wind speed of 7-9 m/s. According to the wind velocity data offered by German Meteorological Service Provider (GMSP) in 2004, shown in figure 13, the average wind speed between 1981-2000 in Feldheim was about 6.4 m/s (GMSP, 2004). However, this wind speed was not very high, but it was close to the optimal value. This might explain why the wind turbines produce about 74 MW yearly.

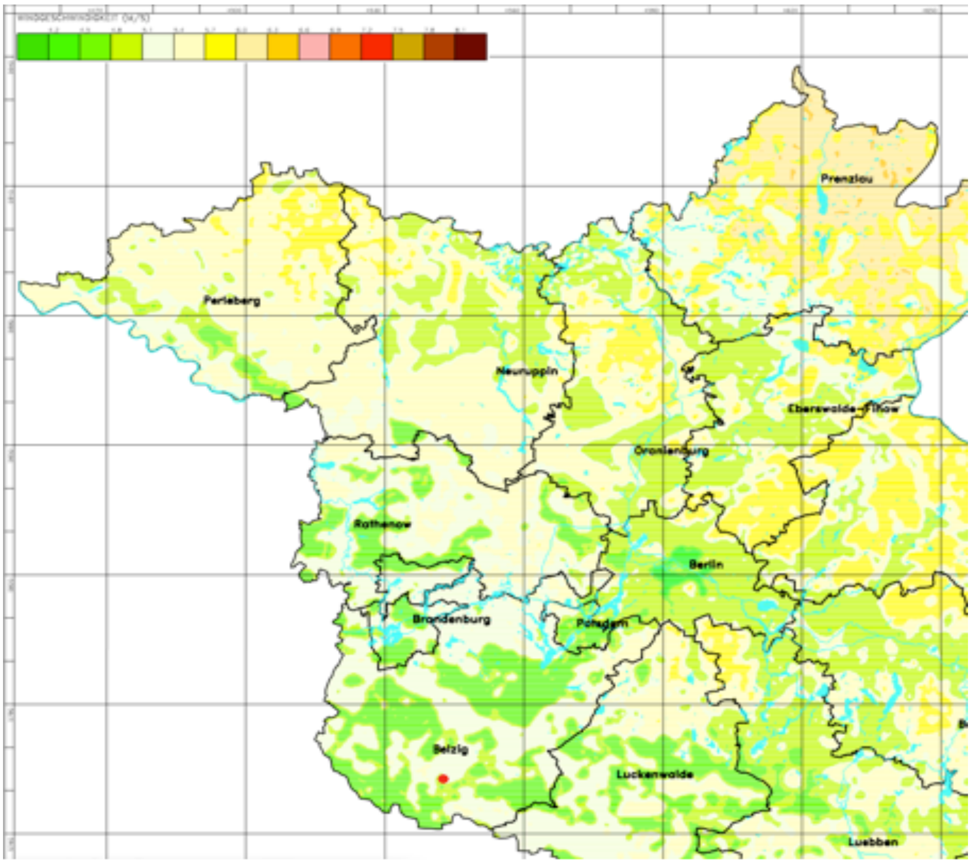

FIGURE 13. Wind map 1981-2000 Brandenburg und Berlin (80 meter) (GMSP, 2004**).**

The success of Feldheim energy self-sufficient eco-village is closely linked with a company, which is called Energiequelle GmbH. About 17 years ago, Energiequelle GmbH approached the municipality to install the first wind turbine in Feldheim. Feldheim has good conditions for wind energy generation, therefore, this area was identified by the regional planning authorities for further wind turbines installation and development. Since that, the company also has helped Feldheim to install other renewable energy projects, from planning phase to construction and maintenance phase. In addition to technical supports, the efforts accounted by Energiequelle GmbH ranged from financing the village to renovate roads, and to new flood lighting for the local football pitch. (Busch &McCormick, 2014.)

4.4 Utilization of renewable energy technologies in Feldheim

The Feldheim energy supply system is unique in Germany due to the separate electricity and heating network. In Feldheim, wind energy as a leading renewable energy technology produces annual 74 MW electricity through the joint operations of 43 wind turbines. Moreover, a solar park with 2.3 MW electricity output and a biogas plant with 500 kW electricity output were installed. A 2 MW battery was installed as back-up system for emergency situation. The Feldheim electricity grid consists of 4600 m high voltage cables and 2600 m medium voltage cables, and the grid is connected to 38 private homes, 2 agricultural units, 3 communal facilities, 1production firm, 1 biogas plant, 1 church and 1 waterworks. In addition to electricity generation, the biogas plant produces about 533 kW of heat capacity, and 295 kW of heat capacity is provided by a woodchip heating plant. (Knape, 2010; Energiequelle, 2014.) A total 3000 m length of local district heating grid is connected with 39 households, 1 farm, 3 pigsties and cowsheds and 1 factory. Detailed information about electricity and heat supply network in Feldheim is shown in figure 14, as well as the coordination between installed renewable energy technologies. (FNEFF, 2012; Energiequelle,2014.)

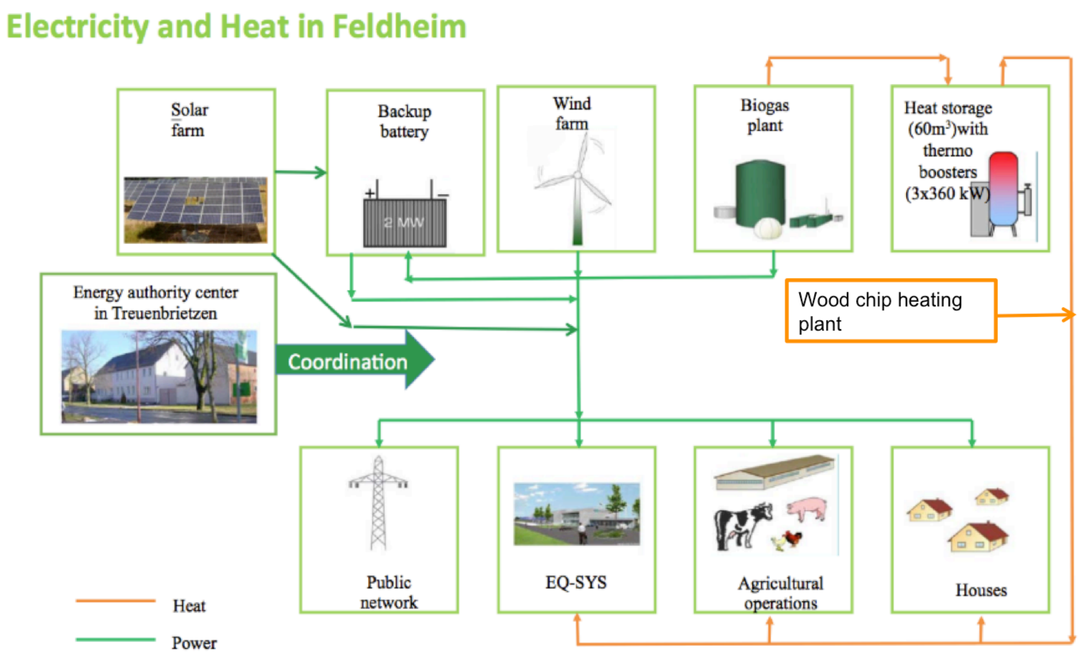

FIGURE 14. Electricity and Heat in Feldheim, modified after the presentation of Energiequelle GmbH (Energiequelle, 2014).

The locations of installed renewable energy plants can be found from figure 15. As it can be seen, most renewable energy plants are implemented close to where the citizens live except wind turbines. This is because of the noise impacts from the operation of wind turbines. However, electricity and heat losses are smaller during transmission if the destinations are close to where electricity and heat produced.

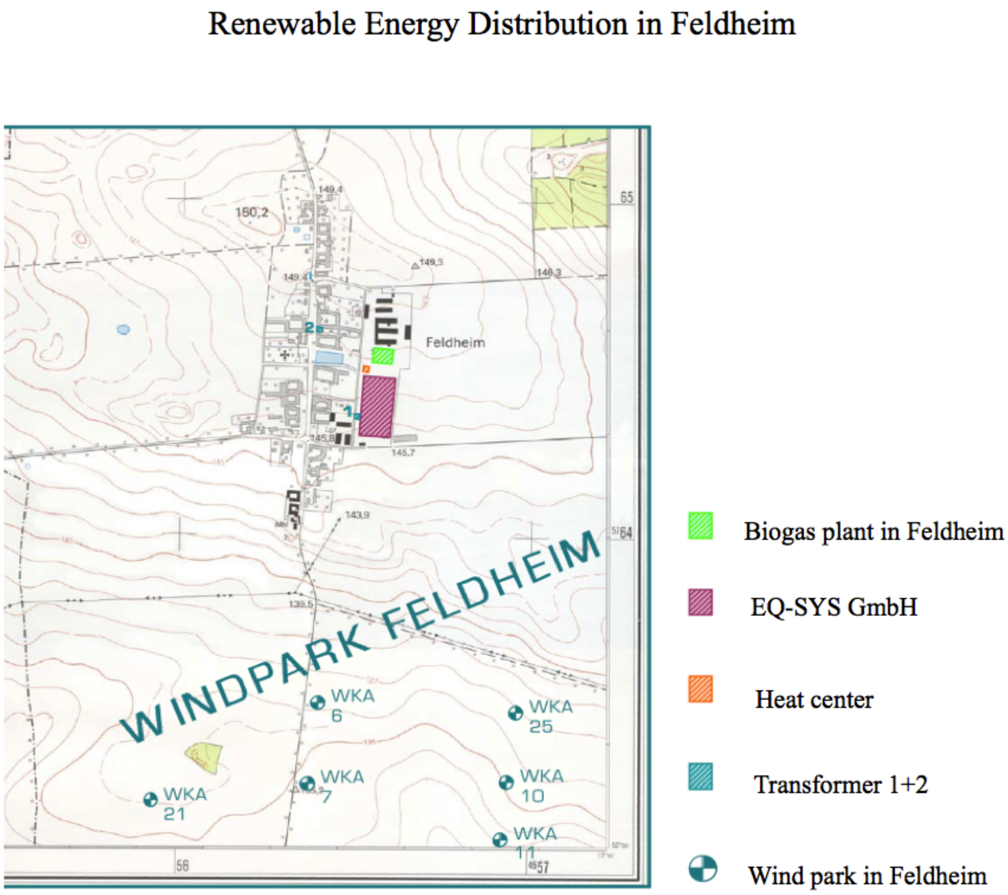

FIGURE 15. Renewable energy distributions in Feldehim, modified after the presentation of Energiequelle GmbH (Energiequelle, 2014).

Other than advanced renewable energy utilization, another reason that made Feldheim so special is that there have been no conflicts about the setup of wind turbines, because citizens of Feldheim are the stakeholders of the Feldheim energy company and also participate in the successful installation of wind turbines. An overall energy cost is 15 % less compared to German standard tariffs. “After the one-time payment of 3000 € for the connection to the heating grid, consumers pay a basic charge of 29.95 € plus 0.075 €/kWh for heat, and 5.95 € plus 0.161 €/kWh for electricity.” The low prices of energy in Feldheim at least stay 10 years. (Knape, 2010.)

4.4.1 Wind energy

At the end of 2009, Germany had a total wind power capacity of about 26 GW which was provided by a total of 21 164 wind turbines, which means that wind-based power takes a dominant position among renewable energy technologies in the aspect of electricity production. Nowadays, wind energy takes more than 7 % share of total electricity consumption in Germany. Since the development of wind power production in Germany, more than 30 million tonnes of CO_2 emissions were reduced. In conclusion, wind energy plays a significant role in achieving the goal of having 30 % increased share of energy generated by renewable sources by the year 2020, where the goal is set by German federal government. (Hasselmann, 2013.)

The construction phase of wind power plants does not require as large amount of energy as construction of conventional power station does. For the wind turbines, the freely available wind is the sole source of energy once they have been installed properly. Depending on the wind characteristics of location, a wind turbine needs three months to one year to produce as much energy as is required to build it. (Hasselmann, 2013.) As mentioned in Section 3.8 Economic factors of wind energy, the normal lifetime of a wind turbine is about 20-25 years (Sorensen, 2009). In the course of its average service life, a wind turbine could generate 40 to 70 times as much energy as was used to manufacture it, install it, use it and dispose it. (Hasselmann, 2013.)

As introduced before, 43 wind turbines with a total electricity output of about 74 MW in Feldheim are operated by the Company Energiequelle GmbH with a separate power grid. The annual amount of electricity produced by wind turbines accounts for a share of 96 % of total amount of electricity demand, and the rest 4 % of total amount of electricity demand can be achieved by the power capacity generated from solar park and biogas plant.

However, all 43 wind turbines were not installed at once. The first wind turbine was commissioned in 1996 and the entire project of energy self-sufficient eco-village was finished in 2010. (FNEFF, 2012.) According to the data published by the database called The Wind Power in March 2013, the presentation of Energiequelle in February 2014 and wind turbines producer Enercon company (The wind power, 2013; Energiequelle, 2014; Enercon, 2014), detailed information of 43 installed wind turbines can be found in table 3, including implemented year, amount and type of installed turbines, diameter, hub height, power of turbines and total nominal power capacity.

TABLE 3. Detailed information of 43 installed wind turbines (The wind power, 2013; Energiequelle, 2014; Enercon, 2014.)

Commissioning year	Amount	Type	Diameter	Hub height	Power of turbine	Total nominal power
1998	1	Enercon E40/500	40 m	-	500 kW	500 kW
1998	1	-		70 m	1000 kW	1000 kW
1998	4	Enercon E66/1500	66 m	85 m	1500 kW	6000 kW
2002	7	-	-	-	1800 kW	12 600 kW
2005	1	Enercon E70/2000	70 m	100 m	2000 kW	2000 kW
2006	26	Enercon E70/E4	70 m	98 m	2000 kW	52 000 kW
At present	3	Enercon E82	82 m	-	2000 kW	6000 kW

As it can be seen, the size of installed wind turbines in Feldheim was increased over last decade in order to achieve more annual electricity output. Since 2005, the maximum power capacity of installed turbines is 2000 kW, which might indicate that the turbines with maximum 2000 kW power capacity probably have been considered the most efficient depending on the wind characteristics in Feldheim region. After the electricity demand is met, the extra electricity output will be fed to national grid. Thus, 2 substations with a capacity of 100 MVA (Mega Volt-Ampere) were installed by Energiequelle company in order to transform the extra power from wind turbines for the local grid and national grid. (Emergieguelle, 2014.)

4.4.2 Solar energy

Solar energy systems are used to convert the direct and diffuse sunlight hitting the earth into heat and electricity energy (Hasselmann, 2013). Sunlight can be converted directly to electricity power by using photovoltaic cells. In 2009, approximately 6.2 TWh of power were provided by photovoltaic cells in Germany, which accounted for a share of 1.04 % of total power consumption in the country. Even though it is a small portion of power consumption compared to wind energy, but the rate is increasing. With the utilization of solar energy, about 3.9 million tonnes of gas emissions (CO_2 equivalents) were reduced in Germany. In figure 12, the irradiation intensity was about 1100-1200 kWh/m^2 in Feldheim region in 2011. Although these values do not precisely make Feldheim to be one of areas with the most abundant solar resource, but it is still possible to develop the solar energy for heat and electricity generation. (Hasselmann, 2013.)

Solar farm is a cluster of many solar panels. The solar farm in Feldheim was named as Selterhof solar farm, this is because the site was ex-military site covering 45 hectares (FNEFF, 2012). The ex-military site was located about 5 miles from Feldheim and it was used for 40 years as a telecommunications center and depot until 1994. (Hasselmann, 2013.) Therefore, before installing the solar farm, Energiequelle had to dismantle 85 buildings and a fueling station and recover the area back to its original natural state. For these reasons, 1.2 million euros was spent on cleaning up the toxic military waste and hidden ammunition (Stone, 2014).

The construction of the solar farm in Feldheim started in 2008. Nowadays, a total number of 9844 photovoltaic modules are mounted on 284 trackers with a total power capacity of 2.3 MW. In addition, the annual power output is enough to cover the annual power demand of approximately 600 4-person households, which equates 2.8 GWh. The solar farm was completely implemented in two phases. The first phase started up in November 2008, and 96 trackers with 34 photovoltaic modules on each tracker were installed and 0.75 MW of total power capacity was generated at then. The enlargements started up in 2009, and 188 trackers were added with a total power capacity of 1.51 MW added. (Hasselmann, 2013.)

All the PV modules are robotic production with twin-axle solar tracking system (EQ-movers) made of steel, and they are produced by EQ-SYS GmbH Ltd. as standard mounting systems. A tracker is a device for holding a solar panel mounted on the ground and orienting a solar panel towards the sun. Through enhancing morning and afternoon performance, a solar tracker can improve the amount of power capacity generated by solar system. A tracker is only needed in the regions with mostly direct sunlight. The height of each installed tracker in Feldheim is about 3.29 m. The 34 installed PV modules on each tracker could reach an area of 60 m^2, 11.74 m× 5.12 m of dimensions. In addition, the total weight of a tracker and installed 34 PV modules is about 3.5 tonnes. (Emergieguelle, 2014.) Figure 16 shows the installed solar energy systems in Feldheim.

FIGURE 16. Installed solar energy systems in Feldheim (Emergieguelle, 2014).

From the social point of view, photovoltaic modules have higher acceptance rate than wind turbines because of the less health impacts concerning the noise produced from the operation of wind turbines, and they are easier to integrate into the building's surface. However, the less efficiency and the big expenditure in manufacturing affect the carbon footprint and the term of amortization adversely.

4.4.3 Biogas plant and woodchip heating plant

Biomass is used for producing energy in biogas plant, including all vegetables and animal excrements, their conversion products and from organic waste suitable for energy extraction. In 2008, the town of Feldheim and Energiequelle established a joint corporation, called Feldheim Energie GmbH & Co. In the same year, a biogas plant was installed with a total capacity of 500 kW with the help of Feldheim Energie GmbH & Co, and the cost of building biogas plant was 1.7 million euros. The plant is operated by the local agricultural cooperatives, and the biogas plant converts pig manure, cattle manure and other organic materials to heat and electricity. (Hasselmann, 2013.) The raw materials are offered by local farming. The annual biomass input is 8 600 m^3 of pig and cattle manure, 8 700 tonnes of maize silage, and 190 tonnes of cereals. As a result, annual electricity output is about 4 GWh and annual heat output is about 4.3 GWh. In addition, annual 15 500 m^3 of fertilizer is produced as output from biogas plant. Approximately 3.76 GWh of generated heat are used for local need for industry and private homes, and the generated electricity is fed into public grid. (Energiequelle, 2014.) In total, about 56 tonnes of heating oil are saved in Feldheim because of the independent heat energy. This is not only benefiting nature, but is also benefiting economic growth. (Hasselmann, 2013.)

In addition to the biogas plant, a woodchip heating plant is installed in Feldheim in order to meet heat demand and guarantee the self-sufficient heat energy. In general, a woodchip heating plant creates heat and electricity as it works similarly with furnace, with an integrated turbine. The hot gases are heating water in high-pressure storages and the steam is carried through a turbine, where the electricity is generated. Afterwards, the remaining heat is fed into the heating grid. Woodchips as raw material can be gained from timber process and it is efficient for heating. (Hasselmann, 2013.)

4.5 Economic factors

Economic factors should be considered as No. 1 driving force for any type of innovation, for instance, investment, payback period, and net profit, etc. Feldheim spent 18 years to complete the entire energy self-sufficient eco-village project, since the first wind turbine was installed completely in 1998 with the help of Energiequelle GmbH, and the project was finished in 2010. In general, 1 725 000 € was spent on the overall investment costs for the heating work and connections, including 138 000 € of limited company resources, 830 000 € of governmental earmarked funds, and the rest of funds from public subsidies (75 % of European funds for regional development; 25 % of state budget) and private loans. Plus, 450 000 € was spent on the overall investment costs for the electricity network and connections, which was completely funded by Feldheim Energie GmbH & Co. KG. (Energiequelle, 2014.)

The investment costs of wind farm should be excluded from the total costs of Feldheim, because Energiequelle GmbH owns the wind turbines as the only owner. Depending on the wind characteristics of location, the payback period of different type of wind turbines are ranging from several months to years. Typically, the sum of investment costs of wind turbines include turbine cost, foundation cost, electric installation, grid-connection, consultancy, land, financial costs and road construction. In addition, turbine cost accounts for a share of 74-82 % of total costs. (European Wind Energy Association, unknown.)

TABLE 4. Estimated total investments (excluded solar farm) of independent energy system in Feldheim (Energiequelle, 2014).

Subject	Investment (million euros)	Funding sources
Biogas plant	1.7	Energiequelle company
Cost of cleaning ex-military	1.2	Energiequelle company
Overall investment costs for the heating work and connections	1.725	limited company resources governmental earmarked funds public subsidies private loans
Overall investment costs for the electricity work and connections	0.45	Feldheim Energie GmbH & Co. KG
Wind farm	57.06-76.33	Energiequelle company
SUM	62.136-81.405	

According to the information offered by a German website (Solar und Windenergie, unknown), the installation cost of a wind turbine with power capacity of more than 1000 kW is about 770-1030 €/kW installed power nowadays. The price has fallen in recent years compared to the price in early 1990's, which was about 1260 €/kW installed power. The driving factors for decreased price are larger volume, optimized production processes and more efficient technology system of production. (Solar und Windenergie, unknown.) Thus, if we calculate the price of 43 installed wind turbines in Feldheim based on the lowest price in recent years, the total price of a total electricity output 74 MW is about 57.06-76.33 million euros. In addition, the cost of installed biogas plant was 1.7 million euros in 2008. The price of solar farm cannot be estimated due to no available published information of installed PV module type. Therefore, the total investments of installed renewable energy systems in Feldheim can be estimated about 62.135-81.405 million euros excluding the costs of solar farm (table 4).

5 POTENTIAL IN CHINA

In order to estimate and assess the potential of building a similar energy self-sufficient eco-village with Fledheim village in China, it is very vital to analyze the geographical peculiarities and climate conditions for wind energy development and other applicable renewable energy systems. This chapter presents wind energy and its potential in China, as well as climate conditions and potential of other renewable energy.

5.1 Wind energy capacity in China

China has been ranked as world leader in wind energy deployment since 2009. Between 2003-2009, Chinese government introduced great deal of interest in the policy measures. These incentive mechanisms and policy choices have promoted its domestic market from being a small-scale wind turbine generator manufacturing country to being a leader in wind energy deployment in global scale. 12.96 GW of new capacity was installed in China in 2012, and wind-generated electricity amounted to 100.4 TWh which accounted for a share of 2 % of the country's total electricity output. (GWEC, 2012.)

Wind energy was the third largest source of electricity after thermal and hydropower in China by the end of 2012, and the total capacity was increased from 25.8 GW in 2009 to 75.3 GW in 2012. Figure 17 shows the increasing trend of total wind installed capacity from 2001 to 2012. (GWEC, 2012.)

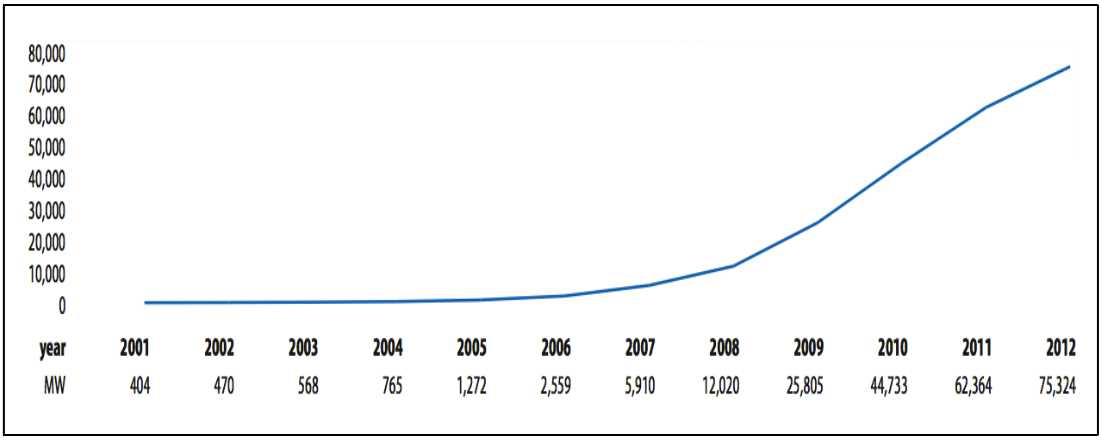

FIGURE 17. Total installed wind power capacity between 2001-2012 in China (GWEC, 2012).

This positive change was achieved due to the government efforts, which aimed at increasing the use of renewable energy in order to reduce carbon emissions, to improve air quality and to cut reliance on fossil fuels. In addition to the electricity generated by wind power, a share of 27.5 % of China's total electricity capacity was generated by other non fossil-fuel sources in 2012. Nowadays, the Chinese wind power market enters to a more steady development and refinement stage, and the ability of managing the grid and system operators becomes new challenge. (GWEC, 2012.)

Wind energy has been developed for years in the country's north, northeastern and northwestern areas because of abundant wind resources. However, the relatively low power consumption and weak grids in those areas have led to wind power spreading to other parts of China, for instance, south western and central west China. Figure 18 shows the cumulative capacity (MW) in top 10 provinces in 2012. It also presents the places that might suit for the establishment of energy independent eco-village with utilization of wind energy. Moreover, the capacity amount might be more in wind rich provinces if the grid infrastructure could be more sufficient.

Top 10 provinces cumulative capacity (MW) in 2012

1	Inner Mongolia	18 624
2	Hebei	7 979
3	Gansu	6 479
4	Liaoning	6 118
5	Shandong	5 691
6	Heilongjiang	4 264
7	Jilin	3 997
8	Ningxia	3 566
9	Xinjiang	3 306
10	Shanxi	2 907

FIGURE 18. Top 10 provinces cumulative capacity (MW) in 2012 in China, modified after GWEC annual report in 2012 (GWEC, 2012).

The National Energy Agency published a proposal of Renewable Energy Portfolio Standard penetration rate for different provinces by the end of 2012, and it aimed at enhancing the development of renewable energy systems depending on local wind and solar resources. Although China is still ranked as world leader at present, many challenges still need to be solved. For instance, lack of finance is becoming a major bottleneck, as well as low capacity of grid and weak interconnection. (GWEC, 2012.)

5.2 Economical aspects of wind energy in China

In 2009，the world average investment costs of onshore wind power plants were estimated about 1200-2100 USD_{2005}/kW on the basis of average annual wind speeds from 6-10 m/s. For onshore wind energy, the world average generation costs were estimated approximately 5-10 US $cents_{2005}$ /kWh in good to excellent wind resource areas, and about 15 US $cents_{2005}$ /kWh in poor wind resource areas. The generation costs of onshore wind energy were cheaper in the USA and China compared to other regions, due to the low investment costs. The average investment costs of onshore wind power plants in China were lower than world average price in 2008 and 2009, and were about 1000- 1350 USD_{2005}/kW. The main reason causing lower investment costs was because of several dominant Chinese wind turbine manufacturers serving the market with lower price. However, the price was increased between 2004-2008 compared to early time. In order to enhance the capacity of modern wind turbines by increasing the size result in increasing costs of raw materials, for instance, steel, copper and carbon fiber. During 2004-2008, it also was the time for strong growth of global economy, thus, the labor cost was high. When financial crisis happened at the end of 2008, the investment costs of onshore wind turbines started to drop. (Wiser& Bolinger, 2010; IPCC, 2011.) Low investment costs and generation costs have became the main economic factors that have enhanced the rapid deployment of wind energy in China since 2009.

5.3 Wind resource in China

To illustrate the huge potential of wind resource and increasing demand of wind power in China, historical and ongoing research are done in order to have better understanding on the characteristics of wind resource. These researches play an important role in the planning and operating stage of establishment of wind power plants, and the potential of wind energy could even affect energy strategy at present and in the future.

China’s Meteorological Administration (CMA) conducted the first assessment of wind resource in the 1970’s. On the basis of the first assessment, the second assessment was done in the 1980’s, which was performed based on data from approximately 900 meteorological stations. At that time, the CMA estimated that the availability of onshore technical potential was 253 GW. (Xue et al., 2001.) The third assessment was based on data from about 2 384 meteorological stations. The data mainly was based on measured wind speeds at 10 m/s, and most data covered a period of over 50 years. An estimate of the availability of 297 GW of onshore technical potential was made based on the third assessment. (IPCC, 2011.)

With improved mesoscale atmospheric models and higher-elevation meteorological data assessment, the higher-resolution assessments are done recently. Figure 19 shows the results of these research focused on onshore technical potential. CMA estimated the availability of onshore and offshore technical potential to be 2 380 GW of and 200 GW respectively. (Xiao et al., 2010.) However, due to its large population and large manufacturing industry, China still faces the great challenge of energy demand and consumption.

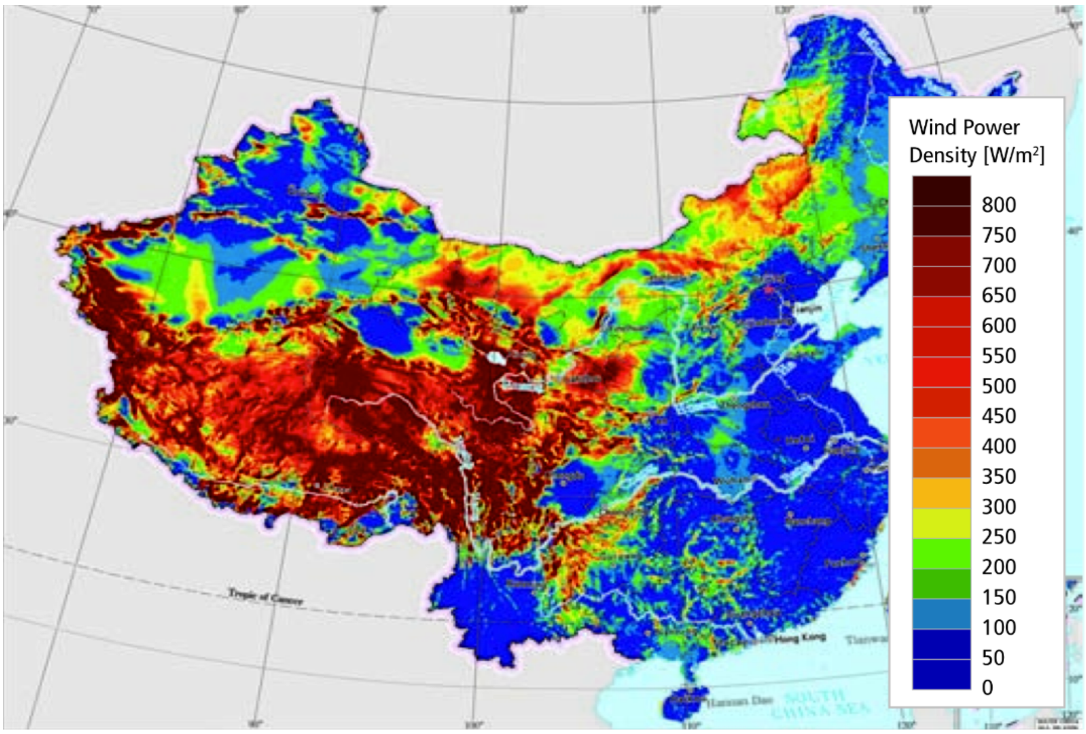

FIGURE 19. Wind resource map for China (Xiao et al., 2010).

Global climate change may influence the geographical conditions and the variability of wind resource, and the prevalence of extreme weather events may impact the design and operation of wind turbines. Therefore, total installed wind power output and potential could be influenced by climate change, due to the changes of wind characteristics. For instance, the changes of wind speed and number of hours of effective wind speed are two major concerns. The influence on wind energy caused by climate change could be long-term. (IPCC, 2011.)

5.4 Climate in China and peculiarities for other renewable energy

The climate in China varies region to region due to the massive land, thus, China has variety of temperature and rainfall zones. Dry seasons and wet monsoons lead to clear temperature difference in winter and summer in China, and to rainfall difference. For instance, the temperature could be about -30 °C in Heilongjiang Province during winter while the temperature could be + 20°C in Hainan Province. In summer, the average temperature in most areas are above + 20°C, but it exceeds + 30°C in Turpan Basin in Xinjiang Province. In general, most areas are cold and dry in winter, and hot and rainy in summer. The climate in China could be classified into six zones according to the temperature and rainfall differences, which are cold-temperature zone, mid-temperature zone, warm-temperature zone, subtropical zone, tropical zone and plateau climate zone. (China travel tour guide, 2013.)

In winter, the weather can be extremely cold in north China and it range from -20 °C in Beijing to -40 °C in further north areas. The temperature could drop below zero in central China and could be above +20 °C in south China. In northwest China and Tibet region, the temperature may drop below -10 °C and -16 °C in winter, respectively. In summer, the temperature could be about +20 °C - +30 °C in north China, and the weather is hot and humid in central China. The temperature can rise around +38 °C in south China. In northwest China, the temperature can reach maximum of about +47 °C during summer, and exceed +29 °C in Tibet region. (China travel tour guide, 2013.)

According to the statistics in 2012 (China Meteorological Administration, 2013), the annual average amount of precipitation was more than normal and the mean temperature was near normal compared to the situation in past years. The average annual precipitation in China was about 670 mm, 20.4 % more than 2011. The precipitation was normal in winter but much more in other seasons. The annual average temperature was about 9.4 °C, which was 0.3 °C less than 2011. The mean temperature was lower than normal in winter and autumn, but higher compared to normal temperature in spring and summer. (China Meteorological Administration, 2013.)

Figure 20 shows the annual irradiation intensity in China. The intensity values range from lower than 2 kWh/m^2/day to higher than 9 kWh/m^2/day on the map, which give information to estimate that the annual irradiation intensity is about 730-3285 kWh/m^2 across China. West China has abundant solar resources and huge technical potential for the development of solar energy systems, especially in southwest China. The annual irradiation intensity in southwest China is about 1656-3285 kWh/m^2. Compared to west China, east China has relatively low annual irradiation intensity, which is only about 730-1095 kWh/m^2. (Openei, 2005.) This is because the weather in east China is more humid than west China since the land is so close to the sea, which offers the condition for more cloud formation.

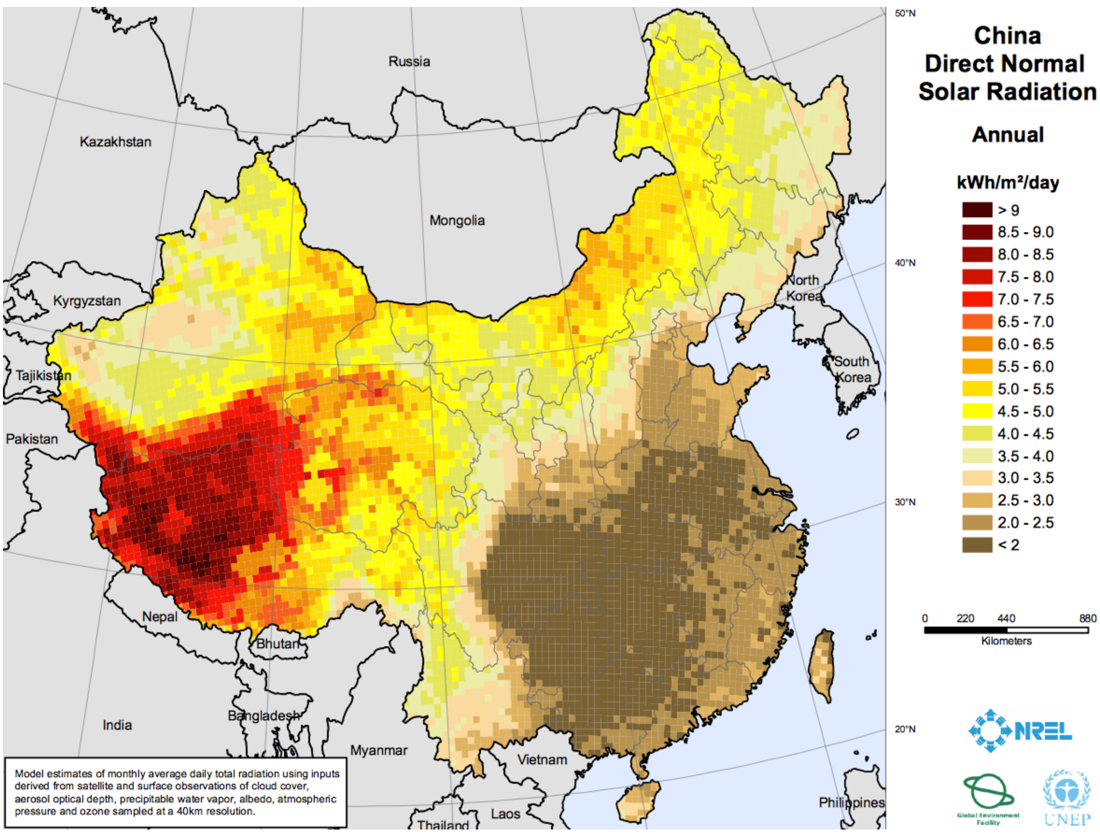

FIGURE 20. The irradiation intensity in China (Openei, 2011).

Based on above climate analysis in China, it can be concluded that the climate conditions in China suit for the development of bioenergy and other renewable energy systems. Many types of organic materials could grow in six temperature zones, and this is the peculiarity of bioenergy power plants operation. In addition, solar energy can also be applied in China due to suitable solar intensity. Overall, climate conditions in China determine that an energy independent eco-village can be built in China as long as government offers technical, financial and social supports.

6 FUTURE DEVELOPMENT OF ENERGY INDEPENDENT VILLAGES

Renewable energy systems are strongly recommended across the world not only because of eco-friendly characteristics, but also as they are nature dependent and inexhaustible, for instance wind energy, solar energy and geothermal energy. Thus, from long-term of view, renewable energy systems have high social and economic value, so as they based villages. In addition to the wind energy emphasized in this thesis, other type of renewable energy systems can be used to build energy independent villages depending on local resources. Small-scale energy self-sufficient villages are the basic unit of sustainability, and the similar concept can be applied for the construction of energy independent communities and buildings depending on local circumstances. If all the communities could reach sustainable energy, then the world will achieve a sustainable brilliant future. This is the deep meaning behind this thesis, which hopes that the thesis could help to raise the individual and public awareness toward to the sustainable energy development.

In order to build an energy independent village/community with efficient renewable energy systems to supply heat and electricity, the first step is to evaluate the local potential for supporting energy self-sufficiency. The core value of energy independence is to use local renewable natural resources to produce “green energy” instead of using traditional fossil fuels. At least, the produced energy should be as much as consumed, so that the village/community will not be a net importer of energy. Thus, the planners should quantify the local energy needs and choose available technologies based on their circumstances. An accurate evaluation provides essential information to determine the suitability of establishing energy independent projects, and helps to predict the beneficial factors and limitations. Additionally, the evaluation of local potential may be of interest to policy makers because it offers the available approach to reach sustainable energy, so as to investors because of the predictable economic and social beneficial factors. Usually, the steps of evaluation process are included as following (IERE, unknown.):

- Define the boundaries of village/community
- Inventory all energy uses, for instance, electricity, natural gas, wood, fuel oil
- Evaluate potential energy systems, for instance, wind, solar, bioenergy
- Match power demands to capacity

In addition to the evaluation of needed energy and available technologies, economic factors are crucial. For instance, how much investments are needed for the implementation of selected renewable energy systems, and what the payback is. As compared earlier, the installation costs and generation costs of wind or other renewable energy systems are higher than the fossil-fuel burning power plants, if the same amount of produced energy is required. The costs to produce renewable energy will be a political decision whether the benefits of an inexhaustible and eco-friendly energy resource is worth the extra expense. (IERE, unknown.)

Nowadays, most of existed successful energy independent villages are distributed in developed countries, for instance, Germany and Denmark. This is because of the foundation of advanced renewable technologies, abundance in capital, governmental incentive mechanisms and policy measures, and higher individual and public awareness toward to the sustainable development. Compared to the wide range of supports in developed countries, although the government has strong desire to achieve sustainable energy in developing countries, but lack of advanced technical supports and finance are two major challenges, as well as relatively low average individual and public awareness. For instance, China has huge potential to establish energy independent projects because some remote areas still cannot access to power supply nowadays or the grid connections are low and not stable. Although China has abundant natural resources and some of renewable energy implementations are ranked as one of world leaders in the world, but the development and utilization of energy self-sufficiency still need to be improved compared to its technical potential.

In the future, lowered investments of renewable energy systems will become the dominant driving factor for enhancing the development of energy independent village/community/building. Additionally, the communication regarding advanced technologies with developed countries will bring technical supports to design and implement more efficient renewable energy systems in developing countries, which could recoup the expensive investment costs by producing more stable electricity and heat output.

7 CONCLUSION

Feldheim has successfully shifted from a normal village to a modern energy self-sufficient eco-village. This is not only because of the successful installed renewable energies, but also the wise and transparent sharing mechanisms between local company, government and villagers. Villagers participated the planning and decision making process and share the economic benefits, thus there was no conflict in renewable energy installation process. The prices for electricity and heat in the village stay at least for 10 years constant and below the regional market.

Moreover, Feldheim has zero unemployment compared with roughly 30 % in other villages in the economically depressed state of Brandenburg, which views investments in renewables as a ticket for a brighter future. About more than 20 new jobs were created in the new established subsidiary company EQ-SYS, and the other citizens could work in the farming or maintain the wind and solar farm. However, without the help from Energiequelle Company and the support from German government, Feldheim probably would not be as successful as it is today. (FNEFF, 2012.)

In addition, Feldheim is open to the world. Every year, tourists across the world come and visit this energy self-sufficient villages, and this would definitely increase the local income in hotel and other travel business sectors in Feldheim even neighbor region. From the environmental point of view, Feldheim saves annually about 56 tonnes of oil fuel because of the independent heat supply. The electricity produced in Feldheim is totally carbon-free. (Hasselmann, 2013.)

Today, there are several similar projects like Feldheim in the world, which supply themselves heat and electricity with renewable energy in a sustainable. But some of them still need to combine renewable energy with official supplier. Thus, off-grid is the most significant characteristic of Feldheim. Overall, the projects like Feldheim energy self-sufficient village can be built elsewhere in the world if the climate characteristics of selected site are similar with Feldheim. The similar energy independent eco-village can be built in China, and the concept can be applied for the construction of eco-community and eco-building. As discussed earlier, the technical supports of planning and implementing the available renewable energy systems and amount of investment costs are two main issues to be solved in accordance with sustainable energy development in developing countries. However, energy independency is a long-term goal in both developed and developing countries, and investors and governments should support associated financial, legal and technical aspects of the further development and innovation.

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